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Source Assessment: Cotton and Synthetic Woven Fabric Finishing

Monsanto Research Corp.
Dayton, OH

Prepared for

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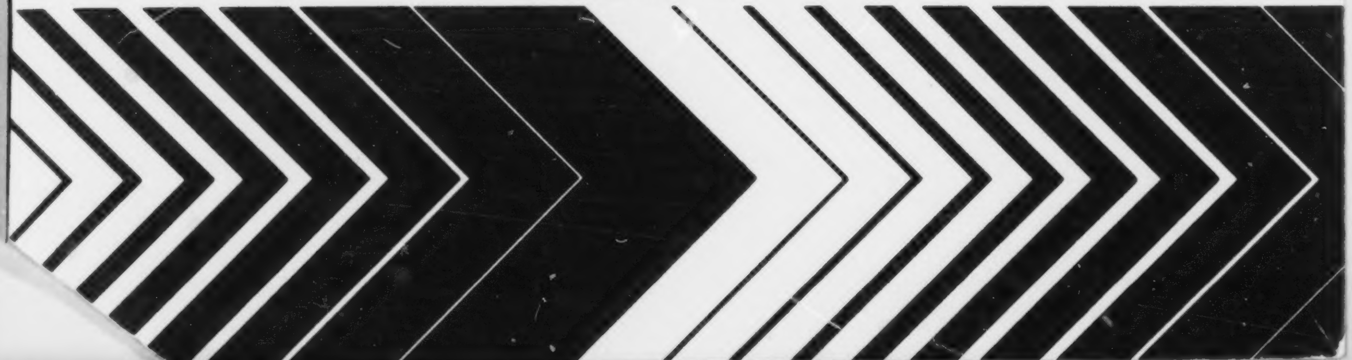

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by

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1515 Nicholas Road
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Contract No. 68-02-1874
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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
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PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and solid waste legislation. If control technology is unavailable, inadequate, or uneconomical, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include: process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

The Chemical Processes Branch of the Industrial Processes Division of IERL has the responsibility for developing control technology for a large number of operations (more than 500) in the chemical industries. As in any technical program, the first question to answer is, "Where are the unsolved problems?" This is a determination which should not be made on superficial information; consequently, each of the industries is being evaluated in detail to determine if there is, in EPA's judgment, sufficient environmental risk associated with the process to indicate that pollution reduction is necessary. This report contains the data necessary to make that decision for air emissions, water effluents, and solid residues from woven fabric finishing manufacturing.

Monsanto Research Corporation has contracted with EPA to investigate the environmental impact of various industries which represent sources of pollution in accordance with EPA's responsibility as outlined above. Dr. Robert C. Binning serves as Program Manager in this overall program, entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. In this study of woven fabric finishing, Dr. Max Samfield of the Industrial Processes Division at Research Triangle Park served as EPA Project Officer.

ABSTRACT

This report describes and assesses the potential environmental impact of air emissions, wastewater effluents, and solid wastes resulting from the woven fabric finishing segment of the textile manufacturing industry. The multimedia emissions characterization identifies all emission points and emission species, determines their emission rates, evaluates the potential environmental effect due to their release, and discusses existing and emerging control technologies.

In terms of air emissions, the primary emission species include particulates, and nonmethane total hydrocarbons. Specific emission species include chlorinated benzenes, phthalate esters, methyl C_{11} to C_{20} esters, benzoic acid, naphthalenes, and aliphatic hydrocarbons. The primary source of these emissions are from dryers associated with heat setting, dyeing, and printing.

Approximately one-third of the woven fabric finishing plants treat their wastewater on-site, the remainder (indirect dischargers) discharge to Publicly Owned Treatment Works (POTW). Criteria pollutants which this industry segment must monitor include 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), chromium, oil and grease, sulfide, phenol, and color. In addition, studies have shown that 1,2,4-trichlorobenzene, ethylbenzene, naphthalene, pentachlorophenol, copper, and zinc are present in the effluent.

Solid waste generated consists of process waste (paper, drums, waste fabric) and sludge from the wastewater treatment plant. Approximately 88% (dry weight) of the waste is process waste. These wastes are disposed of by landfilling, incineration, and land application.

This report, submitted under Contract No. 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency, covers the period from March 1977 to January 1980.

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ABBREVIATIONS AND SYMBOLS

a...f -- constants used in dispersion equations
AA -- atomic absorption
A...F -- atmospheric stability classes
A_a -- area containing the affected population, km^2
AAQS -- ambient air quality standard
A_R -- ratio $Q/ac\pi u$
ASTM -- American Society for Testing and Materials
BOD -- biological oxygen demand
B_R -- ratio $-H^2/2c^2$
C -- confidential
$C_{1,2\cdots n}$ -- organic molecules containing from 1 to n carbon atoms
C_D -- concentration of a pollutant in an effluent, g/m^3
CM -- combustion modification
CO -- carbon monoxide
COD -- chemical oxygen demand
D_P -- population density, persons/km^2
e -- 2.72
EF -- emission factor, g/kg
exp -- exponent of e
F -- hazard factor, g/m^3
F_e -- effluent hazard factor, g/m^3
F_{MZ} -- fraction of river flow in a mixing zone
GC-MS -- gas chromatograph-mass spectroscopy
H -- height of emission release, m
ICAP -- inductively coupled argon plasma
LC_{50}(96-hr) -- concentration lethal to 50% of a group of test organisms in a 96-hr period, g/m^3
M -- molar
NEDS -- National Emissions Data System
NO_x -- nitrogen oxides
NPDES -- National Pollutant Discharge Elimination System
NSPS -- new source performance standards
P' -- total affected population
PCB -- polychlorinated biphenyls
pH -- negative log of the hydrogen ion concentration
POM -- polycyclic organic materials
ppm -- parts per million

ABBREVIATIONS AND SYMBOLS (continued)

Q -- emission rate, g/s
R -- rate of fuel flow
S -- percent of sulfur content of coal
S_a -- source severity of air pollutant emissions
S_{AMZ} -- effluent source severity after the mixing zone
SASS -- source assessment sampling system
S_{BD} -- effluent source severity before dilution
S_{CO} -- source severity of carbon monoxide emissions
S_e -- source severity of an effluent species
S_{HC} -- source severity of hydrocarbon emissions
S_{MZ} -- effluent source severity in the mixing zone
S_{NO_2} -- source severity of nitrogen dioxide emissions
SO_x -- sulfur oxides
S_P -- source severity of particulate emissions
S_{SO_2} -- source severity of sulfur dioxide emissions
t -- averaging time, min
t_o -- short-term averaging time, (3 min)
T.C. -- thermocouple
TDS -- total dissolved solids, g/m^3
TLV -- threshold limit value, g/m^3
TS -- total solids, g/m^3
TSS -- total suspended solids, g/m^3
u -- wind speed, m/s
$\bar{u}$ -- average wind speed, m/s
vr -- river flow rate, m^3/s
V_R -- minimum river flow rate, m^3/s
x -- downwind emission dispersion distance from source of emission release, m
XAD-2 -- resin used for trapping organic emissions
y -- horizontal distance from centerline of dispersion, m
π -- 3.1416
σ_y -- standard deviation of horizontal dispersion, m
σ_z -- standard deviation of vertical dispersion, m
$\bar{\chi}$ -- time-averaged ground level concentration of an emission, g/m^3
χ_{max} -- instantaneous maximum ground level concentration, g/m^3
$\bar{\chi}_{max}$ -- time-averaged maximum ground level concentration, g/m^3

SECTION 1

INTRODUCTION

The purpose of this study was to characterize air emissions, wastewater effluents, and solid residues resulting from the woven fabric finishing segment of the textile manufacturing industry. This industry segment is represented by Standard Industrial Classification (SIC) Codes 2261 and 2262 and includes finishing of broadwoven fabrics made of cotton and synthetic fibers.

The report contains a source description that defines process operations, process chemistry, plant capacity, and general source locations. The multimedia emissions characterization identifies all emission points and emission species, determines their emission rates, and evaluates the potential environmental effect due to their release. Present and emerging control technologies are also discussed.

In this industry segment, the principal process unit operations include desizing, scouring, bleaching, mercerizing, heat setting, dyeing, printing, and adding special finishes. A large variety of chemicals are used in each unit operation throughout the industry. Because of the variety of chemicals used and the large number cf ways the unit operations are arranged in order to process different products, no two woven fabric finishing plants are identical.

Therefore, the assessment approach utilized throughout the report is to discuss each unit operation, the type of emissions which may be emitted by each operation, and then assess the industry emissions across the industry as a whole by using maximum, minimum, and mean values to report ranges of emissions and potential environmental impacts.

The main body of the report consists of five separate sections. Section 2 presents a summary of the major findings of the study. Section 3 presents a detailed description of the processes used in woven fabric finishing and a general description of the industry. Information on the nature of discharges, their environmental impact, and applicable control technologies are presented in Sections 4, 5, and 6 for air emissions, wastewater effluents, and solid wastes, respectively.

SECTION 2

SUMMARY

This document characterizes and assesses the potential environmental impact of air emissions, wastewater effluents, and solid residues released to the environment by the woven fabric finishing segment of the textile manufacturing industry. This industry segment is principally represented by SIC Codes 2261 and 2262. Further, this study focuses only on those mills classified as wet, since the dry mills are considered to have little air emission and no wastewater discharge.

Of the 336 woven fabric finishing mills considered in the study, 46% were located in the states of Alabama, Georgia, North Carolina, and South Carolina. Another 25% were located in the northeastern states of Connecticut, Maine, Massachusetts, Rhode Island, New Jersey and New York.

Woven fabric finishing operations are performed using many combinations of the following units operations: desizing, scouring, bleaching, mercerizing, heat setting, dyeing, printing, and other special treatments that impart to the fabric one or more of the following properties: water repellence, soil repellence, flame retardance, shape retention, static resistance, abrasion resistance, and germicidal and fungicidal characteristics. The operations that any single manufacturing plant may use depend on the type of fiber used and the product end use.

In terms of air emissions, the principal sources include vents and exhaust hoods from the drying, singeing, scouring, desizing, bleaching, dyeing, and printing operations. Since there was only a small amount of air emissions data available in the open literature, MRC conducted a comprehensive organic analysis of air emissions from four typical woven fabric finishing plants. Samples of off-gases were collected from heat setting, Thermosol dyeing, finishing on a tenter frame, and curing of finished goods in a curing oven. Average emission factors were determined for these sources and are presented in Table 1.

The potential environmental effect of air emissions from typical woven fabric finishing plants was evaluated using source severity, S_a, defined as the ratio of the time-averaged maximum ground level concentration ($\bar{\chi}_{max}$) to an appropriate hazard factor (F). The values of $\bar{\chi}_{max}$ were calculated from accepted plume dispersion

TABLE 1. SUMMARY OF PROCESS RELATED AVERAGE AIR EMISSION FACTORS FROM FOUR WOVEN FABRIC FINISHING PLANTS

	Emission factor by source type, mg/kg of fabric			
Emission species	Heat setting	Thermosol dyeing	Resin finishing tenter frame	Resin finishing curing oven
Particulate	290	230	560	160
Total nonmethane hydrocarbon	645	480	3,160	2,600
Phthalate esters	0.2-1.3	0.1-2.3	0.6-130	0.01-2
Methyl myristate	-[a]	0.3	1.1	1.9
Methyl palmitate	4.9	13	4.3	24
Methyl stearate	12	18	5.3	31
Methyl C_{11} to C_{20} esters	0.3	0.4-4.0	0.5	
Aliphatics (C_{12}-C_{34})	150	22	140	69
Naphthalenes		0.01-3.0	1-11	0.3-3
Dichlorobenzene		1.6	16	0.06
Trichlorobenzene		0.7	380	0.06
Butyl benzoate		10	320	600
Biphenyl		3	50	3.3
Anthraquinone		9.6	3.1	6.5
Benzoic acid			7	130

[a] Blanks indicate species not detected.

equations and emission factors determined from the field sampling program. The hazard factor is defined as the primary ambient air quality standard in the case of particulates and total nonmethane hydrocarbons and as a reduced threshold limit value (TLV®), F = TLV x 8/24 x 1/100, for other emission species. The factor 8/24 adjusts the TLV for a 24-hr exposure while 1/100 is a safety factor.

The resulting source severity factors for an average plant producing 11,400 mg/yr are shown in Table 2. The source severities for all other emission species was less than 0.001.

TABLE 2. SOURCE SEVERITY VALUES FOR AN AVERAGE PLANT

	Source severity			
Emission species	Heat setting	Thermosol dye range	Resin finishing tenter frame	Resin finishing curing ovens
Particulate	0.03	0.03	0.06	0.02
Total nonmethane hydrocarbon	0.17	0.12	0.82	0.68

In terms of wastewater, eight unit operations within a woven fabric finishing plant generate wastewater: desizing, scouring, bleaching, mercerizing, dyeing, printing, functional finishing, and sanitary wastes. At all mills the various wastewaters are collectively treated on site or passed to a Public Owned Treatment Works (POTW) for treatment. Therefore, instead of assessing effluents from each process unit operation, this study focused on the range in effluent quality and quantity across the industry.

The basic wastewater treatment plant employed for textile wastewater from direct dischargers consists of screening, activated sludge (using surface aeration), clarification and chlorination. The range in final effluent pollutant discharge factors for the criteria pollutants and priority pollutants across the industry is given in Table 3.

TABLE 3. SUMMARY OF EFFLUENT DISCHARGE FACTORS AND SOURCE SEVERITIES

Pollutant parameter	Discharge factor g/kg of fabric	Effluent source severity
BOD_5	2.1-4.1	0.01
COD	29-39	0.04
TSS	4.6-7.6	<0.001
Oil and grease	1.0	0.5
Phenol (total)	2.8-17	0.03
Chromium (total)	2.5-3.7	0.05
Sulfide	10-90	0.09
Color, APHA units	100-300	-[a]
1,2,4-trichlorobenzene	2.2	0.001
Ethylbenzene	3.1	0.004-0.036
Naphthalene	0.3	0.003
Pentachlorophenol	0.18	0.005-0.034

[a] No criteria are available by which to calculate a severity.

As in the case of air emissions, source severity values for pollutants in wastewaters were also calculated. The relationship is the ratio of mass of pollutant discharged in the effluent to the mass the receiving stream can accept:

$$S_e = \frac{V_D C_D}{V_R F} \qquad (1)$$

where S_e = source severity for a pollutant,
V_D = wastewater effluent flow rate, m^3/s
C_D = concentration of pollutant in wastewater, g/m^3
V_R = volumetric flow rate of receiving body, m^3/s
F = hazard factor for a pollutant, g/m^3

The hazard factor is more complicated to calculate for pollutants in water than in air because it is directly related to toxicology data, if the data are available. Results of the source severity calculations for the principal pollutants are also given in Table 3.

Solid waste generated at woven fabric finishing plants consist of process waste and sludge from the wastewater treatment plant. In 1977 it was estimated that 37,702 Mg (dry weight) of solid waste was generated, of that total, 88% was process waste (paper, drums and waste fabric).

The process related wastes are currently being disposed by landfill and incineration, both on-site and off-site. Sludges from the wastewater treatment plants are being stored in lagoons, incorporated into agricultural soil, and landfilled. The principal concern from sludges are potential leachates consisting of higher concentrations of trace metals, such as chromium, copper, sodium, and zinc.

SECTION 3

SOURCE DESCRIPTION

INDUSTRY DESCRIPTION

The textile manufacturing industry is to converts natural and man-made fibers into fabrics and other textile products. Fibers are processed into yarns which are woven, knit, or otherwise processed into fabrics. Figure 1 illustrates the distribution of fiber types used to produce yarns [1]. The fabrics are then dyed, printed, and/or finished.

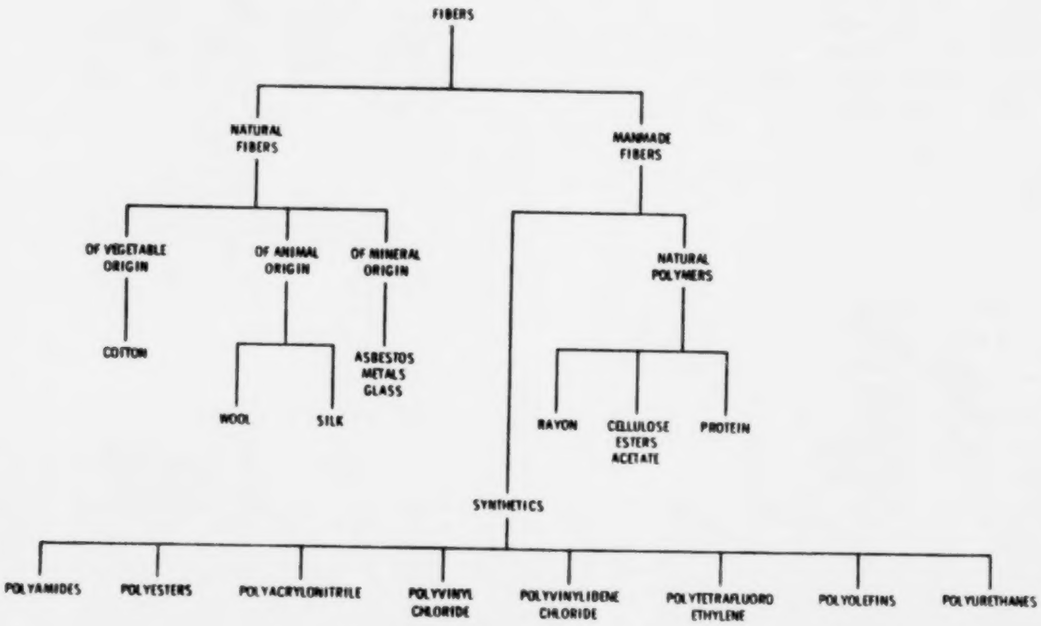
FIBERS
NATURAL FIBERS
MANMADE FIBERS
OF VEGETABLE ORIGIN
OF ANIMAL ORIGIN
OF MINERAL ORIGIN
NATURAL POLYMERS
COTTON
WOOL
SILK
ASBESTOS
METALS
GLASS
RAYON
CELLULOSE ESTERS ACETATE
PROTEIN
SYNTHETICS
POLYAMIDES
POLYESTERS
POLYACRYLONITRILE
POLYVINYL CHLORIDE
POLYVINYLIDENE CHLORIDE
POLYTETRAFLUORO ETHYLENE
POLYOLEFINS
POLYURETHANES

Figure 1. Fiber construction [1].

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[1] Current Industrial Reports. Broadwoven Fabrics Finished, 1974. Series MA-225(75)-1, U.S. Department of Commerce, Washington, D.C., June 1975. 5 pp.

Finished fabrics are then converted by the Apparel industry into apparel or into household, commercial, or industrial products such as upholstery, sheeting, and draperies.

In the United States the textile manufacturing industry is covered by one of the twenty major groups of manufacturing industries in the SIC: Major Group 22, Textile Mill Products. A breakdown of Major Group 22 by four-digit SIC codes is given in Table 4 [2]. The table also shows the number of establishments reported in each subclassification.

The SIC code system is designed to keep track of the flow of goods and products throughout the United States and is primarily structured around products produced. Therefore, this code system is not particularly useful for evaluating emissions from specific unit operations or systems of operations. Table 4 illustrates this point by showing industry segments which use similar unit processes and the appropriate SIC code.

TABLE 4. GENERAL STATISTICS - TEXTILE MILL PRODUCTS MAJOR INDUSTRIAL GROUP [2]

Industry segment	SIC code	Establishments total
Weaving mills, cotton	All Group No. 221	307
Weaving mills, synthetics	All Group No. 222	412
Weaving and finishing mills, wool	All Group No. 223	198
Narrow fabrics mills	All Group No. 224	376
Knitting mills (including finishing)	All Group No. 225	2,723
Hosiery mills	2251, 2252	727
All other knitting mills	2253, 2254, 2257, 2258, 2259	1,996
Finishing mills, excluding wool and knits	All Group No. 226	656
Broad woven fabric	2261, 2262	455
Stock, yarn, narrow fabric, etc.	2269	201
Floor covering mills	All Group No. 227	529
Yarn and thread mills	All Group No. 228	810
Miscellaneous textile goods	All Group No. 229	1,193
Felt goods	2291	47
Nonwoven good	2297	82
Wool scouring and NEC[a] goods	2299	345
Other miscellaneous Textile products	2292, 2293, 2294, 2295, 2296, 2298	719
Textile industry - all segments	Major Group No. 22	7,204

[a] Not elsewhere classified.

Many studies have categorized the industry based on similar unit operations and sources of emissions [2-5]. The most recent attempt to categorize the industry for environmental assessment purposes was by Sverdrup and Parcel and Associates, Inc. [2]. Under contract with the U.S. Environmental Protection Agency (EPA), Effluent Guidelines Division, they collected data from the industry to support EPA in issuing effluent limitation guidelines, new source performance standards, and pretreatment standards. The resulting subcategorization and respective number of plants is shown in Table 5.

TABLE 5. SURVEY STATUS SUMMARY - MILLS ON MASTER LIST [2]

Manufacturing segment	Total mills listed
Wool scouring	17
Wool finishing	37
Low water use processing	808
Woven fabric finishing	336
Knit fabric finishing	282
Hosiery finishing	160
Carpet finishing	58
Stock and yarn finishing	217
Nonwoven manufacturing	38
Felted fabric processing	20
Total	1,973

Because many textile plants perform more than one operation, the 7,204 establishments are located at 5,500 individual plant sites. Of the 5,500 mills in Major Group No. 22, Sverdrup and Parcel found that 3,527 were either closed or classified as having dry operations - meaning no process water discharged. The remaining 1,973 mills were classified as wet processes and were included in their study [2].

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[2] Sverdrup & Parcel and Associates, Inc. Technical Study Report BATEA-NSPS-PSES-PSNS Textile Mills Point Source Category. Contract 68-01-3289 and 68-01-3884, U.S. Environmental Protection Agency, Washington, D.C., November 1978.

[3] Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Textile Mills Point Source Category. EPA-440/1-76-002a, U.S. Environmental Protection Agency, Washington, D.C., June 1974. 241 pp.

[4] Cooper, S. G. The Textile Industry, Environmental Control and Energy Conservation. Noyes Data Corporation, Park Ridge, New Jersey, 1978. 384 pp.

[5] Environmental Pollution Control Textile Processing Industry. EPA-625/7-78-002, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1978. 523 pp.

SOURCE DEFINITION

This study assesses the potential environmental effects from only one segment of the textile manufacturing industry, woven fabric finishing (basically SIC subclassifications 2261 and 2262). Woven fabric finishing mills classified as dry operations include unit operations such as spinning, tufting, and texturizing. These mechanical operations have no aqueous emissions and are considered to have little air emission [2-4]. Therefore, this study concentrates on the woven fabric finishing industry classified as wet and uses the industry description recently compiled for EPA and reported in Reference 2.

The geographical distribution of the industry by EPA regions is shown in Table 6 [2]. Of the 336 woven fabric finishing mills, 155 (46%) are located in EPA Region IV, particularly in the Carolinas and Georgia. Another 25% are in the northeast (New England, New Jersey, and New York).

TABLE 6. GEOGRAPHICAL DISTRIBUTION - MILLS ON MASTER LIST [2]

Manufacturing segment	EPA region										Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	
Wool scouring	6	1	3	3	0	3	0	0	0	1	17
Wool finishing	20	2	4	3	1	1	1	1	0	4	37
Low water use processing	86	108	125	463	11	8	1	0	4	2	808
Woven fabric finishing	69	54	34	155	11	3	1	2	7	0	336
Knit fabric finishing	27	58	45	134	9	1	2	0	6	0	282
Hosiery finishing	2	2	9	139	5	2	0	0	0	1	160
Carpet finishing	0	1	4	39	1	4	0	0	9	0	58
Stock and yarn finishing	33	19	31	120	6	3	1	0	4	0	217
Nonwoven manufacturing	10	3	4	11	7	2	0	0	1	0	38
Felted fabric processing	7	2	3	3	2	0	0	0	3	0	20
Total	260	250	262	1,070	53	27	6	3	34	8	1,973

Table 7 gives the distribution of plants by plant size, expressed in terms of production exposed to wet processing [2]. Wet production is dependent on the weight of material in the final product and it may be noted in the table that mills producing light weight products such as hosiery and other sheer knit goods occupy the smaller production ranges. The woven fabric finishing industry contains twice as many mills as any other segment processing greater than 34 mg/day.

PROCESS DESCRIPTION

Woven fabric finishing operations are performed using many combinations of the following unit operations: desizing, scouring, bleaching, dyeing, printing, heat setting, drying, singeing, and other special treatments that impart to the fabric one or more of the following properties: water repellence, soil repellence, flame retardance, shape retention, static resistance, abrasion resistance, and germicidal and fungicidal characteristics. The operations that a particular fabric undergoes in a finishing plant depends on the class of fiber (natural, man-made, or blend) and fabric end use.

A generalized process flow diagram for a woven fabric finishing plant is shown in Figure 2 and is applicable for processing cotton, man-made, and/or blended fiber fabrics [6]. Depending on the fabric and its end use, one or more of the unit operations may be deleted from the system. There are many information sources which describe in detail all of the unit operations and combinations of unit operations associated with woven fabric finishing [2-5, 7-9]. This section briefly describes each unit operation and its source and type of emissions.

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[6] Corbman, B. P. Textiles: Fiber to Fabric, 5th Edition. McGraw-Hill Book Company, New York, New York, 1975. 568 pp.

[7] Wright, M. D., S. D. York, III, and J. J. Kearney. Prioritization of Emissions from Textile Manufacturing Operations on the Basis of Potential Impact of New Source Performance Standards. Contract No. 68-02-2612, Task 64, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1979. 76 pp.

[8] Mathews, J. C., G. E. Weant, III, and J. J. Kearney. Screening Study on the Justification of Developing New Source Performance Standards for Various Textile Processing Operations. Contract 68-02-0607, Task 11, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, August 1974. 110 pp.

[9] Collins, L. H. Control Technology Assessment of Selected Processes in the Textile Finishing Industry. Contract No. 210-76-0176, National Institute for Occupational Health and Safety, Cincinnati, Ohio, February 1978. 218 pp.

TABLE 7. PRODUCTION SIZE - MILLS ON MASTER LIST [2]

Manufacturing segment	Mills within given production range, mg/day											
	0-2	2-4	4-9	9-13	13-22	22-34	34-45	45-68	68-91	91+	Unknown	Total
Wool scouring	2	3	0	1	4	2	2	2	0	0	1	17
Wool finishing	8	9	9	2	1	2	2	0	0	0	4	37
Low water use processing	10	7	11	19	23	21	7	5	3	2	700	808
Woven fabric finishing	36	27	33	28	33	21	20	12	9	21	96	336
Knit fabric finishing	43	26	34	29	48	21	7	9	5	1	59	282
Hosiery finishing	94	25	10	5	2	0	0	0	0	0	24	160
Carpet finishing	2	2	7	3	8	5	6	7	5	5	8	58
Stock and yarn finishing	32	47	35	23	25	20	6	7	1	2	19	217
Nonwoven manufacturing	3	3	2	4	3	5	2	2	0	1	13	38
Felted fabric processing	6	5	2	1	0	0	0	1	0	0	5	20
Total	236	153	143	115	147	97	52	45	23	32	929	1,973

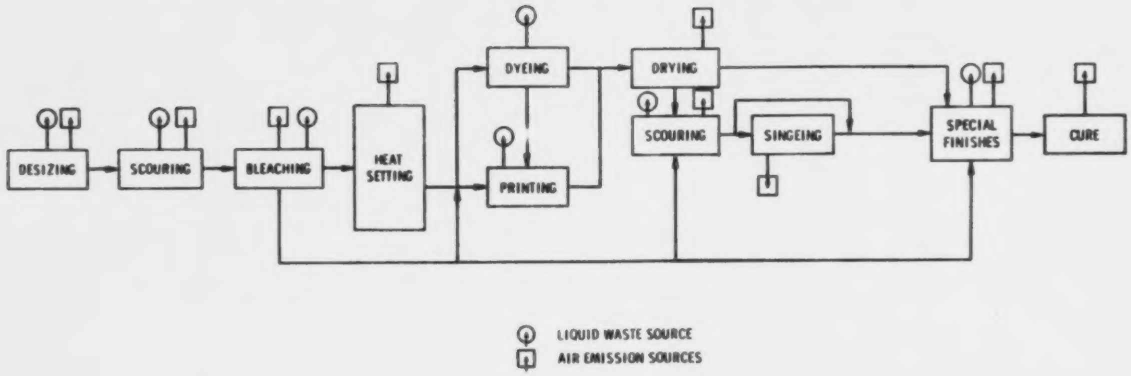
DESIZING
SCOURING
BLEACHING
HEAT SETTING
DYEING
PRINTING
DRYING
SCOURING
SINGEING
SPECIAL FINISHES
CURE
LIQUID WASTE SOURCE
AIR EMISSION SOURCES

Figure 2. Woven fabric finishing process [6].

Desizing

Following singeing, a desizing operation is performed to remove the size applied in the slashing operation at the weaving mills and is usually the first wet finishing operation performed on woven fabric. The function of the size is to impart strength to the thread so that it withstands the abrasion and friction encountered during the high speed mechanical weaving operations [10].

The desize solution can be enzymatic or acidic. Enzyme desizing solubilizes the size using complex organic compounds (malt extracts) dissolved in a solution containing salt (NaCl, KCl, $CaCl_2$ or KNO_3) and a penetrant. The fabric passes through the desizing bath, which is maintained at 55°C to 85°C [10]. Acid desizing utilizes a sulfuric acid bath that is held at room temperature. After running through one of the above-mentioned baths, the fabric is stored in bins, tile-lined pits, or in J-boxes. The fabric remains in these enclosures for 1/2 hr to 12 hr in a moist state to allow time for the desizing agent to act [10]. The fabric is then rinsed free of excess materials.

If polyvinyl alcohol or any other synthetic size is present on the woven fabric, hot (190°F) detergent solutions are used as the desizing medium.

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[10] Merril, G. R., A. R. Macormac, and H. R. Mauersberger. American Cotton Handbook, 2nd Edition. Textile Book Inc., New York, New York, 1949. 943 pp.

There are two post-desizing operations. The desized goods are passed through a caustic bath and a penetrant bath to ready them for scouring [11].

Scouring

In the scouring operation, spinning oils, wax, dirt, and grease are removed by cooking the fabric in a hot, alkaline detergent or soap solution. Pressure kier boiling and continuous atmospheric pressure scour are two methods in use today for cotton fabrics; the latter process is becoming more prevalent because it requires less time.

Pressure kier boiling utilizes a cylindrical pressure vessel (kier), 1.8 m to 2.7 m in diameter and 3.0 m to 3.7 m high. Approximately 1,800 kg to 4,500 kg of the fabric is plaited down in the kier [10]. Preheated alkaline scouring agent, containing sodium hydroxide, sodium carbonate, sodium silicate, pine oil soap, and fatty alcohol sulfates [12], is added and undergoes constant recirculation through the tank throughout the process.

Cooking is performed at 120°C and 34 kPa to 100 kPa (5 psi to 15 psi) for 2 hr to 12 hr. When the operation is concluded, the scouring liquid is drained and the fabric rinsed, first with hot water and then with cold [12].

In continuous ambient pressure scouring, the fabric is saturated with a caustic solution and plaited down into a J-box where its detention is about 1 hr. While the fabric is situated in the J-box, it is heated to a temperature of 99°C to 102°C with steam. Following the passage of the cloth through the J-box, the heated fabric is rinsed of scouring solution [10].

For polyester and cotton/polyester blends, four methods of scouring in open-width form are used: 1) utilization of jigs or becks, 2) continuous range operations, 3) batch operations using baths, and 4) jet scouring operations [13-15]. All of these operations entail cleansing the fabric with a weak alkaline, detergent solution. Kier boiling with caustic soda is not performed on polyester fabrics because fiber degradation occurs as a result of polyester polymer hydrolysis.

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[11] Schelsinger, H. A., E. F. Dill, and T. A. Fridy, Jr. Pollution Control in Textile Mills. In: Industrial Pollution Control Handbook, Chapter 15, Herbert F. Lund, Ed. McGraw-Hill Book Company, New York, New York, 1971. 30 pp.

[12] State of the Art of Textile Waste Treatment. EPA-12090 ECD 02/71 (PB 212 359), U.S. Environmental Protection Agency, Washington, D.C., February 1971. 348 pp.

Solvent scouring is one alternative method to the alkaline wet-process [13]. Three solvents used in the scouring of fabrics are perchloroethylene, trichloroethylene, and 1,1,1-trichloroethane.

In general terms, the solvent scouring process involves saturation of the fabric with solvent and the subsequent removal of the solvent by passing the fabric through a steam or hot water chamber. Solvent is continuously purified by filtration or distillation [13].

Figure 3 illustrates a typical continuous scouring and bleaching operation [10].

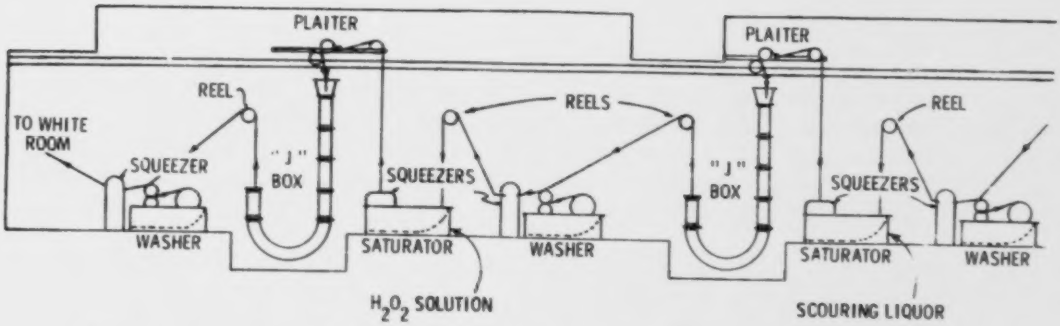

Figure 3. Continuous scouring and bleaching range [10].

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[13] Davis, J. W. The Preparation and Dyeing of Polyester-Cotton Fabrics. Journal of the Society of Dyers and Colourists, 89(3):77-80, 1973.

[14] Forrester, R., L. Wellingham, and G. Gambino. How to Prepare, Dye, and Finish Textured Polyester Woven Fabrics. American Dyestuff Reporter, 63(10):27-43, 1974.

[15] Sturkey, W. Preparing, Dyeing, and Finishing textured Polyester Woven Fabrics. American Dyestuff Reporter, 62(1):42-45, 1973.

Bleaching

Following scouring, the fabric preferably undergoes bleaching in which the natural yellowish shade of the fabric is removed and replaced with a highly intense, white color. The operation can be performed in bins, jigs, or on a continuous basis [10].

One of three bleaches is used in finishing cotton: sodium hypochlorite, chlorine, or hydrogen peroxide. When sodium hypochlorite is the bleaching agent, the fabric is rinsed in water, passed through a bath of sulfuric or hydrochloric acid, and rinsed in water again. In a batch operation, fabric passes through the hypochlorite solution, a slight padding is applied to achieve a uniform distribution of the solution, and the product is stored in white bins for up to 24 hours at 13°C to 19°C [11]. The fabric is finally rinsed and moved on for further finishing.

When the continuous bleaching method is practiced, hydrogen peroxide is commonly used as the oxidizing agent. This operation is usually conducted in conjunction with a continuous scouring operation. The bleaching process involves a rinse, saturation with an alkaline peroxide solution, and a detention period in the J-box. The cloth then undergoes final rinses.

Heat Setting

Heat setting is used on synthetic fabrics and cotton/synthetic blended fabrics in order to stabilize shrinkage which may occur as a result of exposure to hot solutions and drying operations in subsequent process steps. Steam or hot air at 200°C is used to transfer heat to the cloth. After emerging from this step, the dimensional stability of the fabric will not change unless the operation is repeated at a higher temperature [4, 16].

Mercerizing

Mercerization is conducted to increase the luster, strength, and dye affinity of the fabric. Fabric mercerization is a continuous process utilizing padding mangles, a tenter frame, and a number of boxes for rinsing and scouring (an acidic rinse). The process entails the saturation of the cloth with sodium hydroxide, stretching the cloth while it is saturated, and the removal of the alkaline solution before releasing the tension. The fabric is then rinsed and scoured. The padder's function is to achieve

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[16] Wastewater Treatment Systems: Upgrading Textile Operations to Reduce Pollution. EPA Technology Transfer Seminar Publications, EPA-625/3-74-004, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1974. 45 pp.

uniform saturation of the fabric with the alkaline mercerizing solution. Wetting agents are added to the solution to aid penetration. The tenter frame stretches the fabric while the caustic solution is acting. The final stage of the operation involves three rinsing boxes. The first rinse box contains warm water; the second, a weak sulfuric acid solution; and the third, cold water [10].

Mercerization wastes are predominantly the sodium hydroxide used in the process, diluted as a result of the washing step. The waste stream contains high levels of dissolved solids and may have a pH of 12 to 13. Depending on whether mercerization is practiced before or after bleaching, small amounts of foreign material and wax may be removed from the fiber and will appear as suspended solids and oil and grease. In total, mercerization has been found to contribute about 1 percent of the BOD load generated during the processing of 100 percent cotton woven fabric [2].

Today, with synthetics and cotton-synthetic blends replacing 100 percent cotton fabric, mercerization is practiced less often. Most of the mills that do utilize the process have found it economically attractive to recover sodium hydroxide for reuse. Consequently, the waste contribution from the process has become even less significant at many mills.

Dyeing

There are several methods used commercially in dyeing woven fabrics. The process involves fixing a dye on the fabric to obtain the desired shade and the best resistance to color-destroying factors. Besides the obvious use of dyes in this operation, two kinds of dyeing assistants are also utilized: retarding agents, and exhausting agents. Retarding agents prevent quick fixation to the fabric, which would result in uneven dyeing. Exhausting agents cause the dye to be firmly attached to the fibers. Piece dyeing, the general term used to refer to the dyeing operation as it is conducted in the finishing plant, is performed utilizing beck, jig, jet, or pad dyeing machines. Some fabric is dyed using dyebaths or beam dyeing machines that are operated batchwise. Continuous operations involve the utilization of thermosol or thermofix dyeing equipment [10].

The procedure basically involves completion of the following steps [17]:

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[17] Cook, G. Man-made fibers. In: Handbook of Textile Fibers, 4th Edition, II. Morrow Publishing Company, Ltd., Watford Herts, England, 1968. 895 pp.

- impregnation of fabric with dye
- fixation of dye on fiber Singeing
- removal of unreacted dye liquor by washing
- drying or curing

Six types of dyes used are: disperse, vat, sulfur, naphthol, pigment, and reactive [10]. Table 8 shows the relative amounts of each dye used in a typical cotton dyehouse (personal communication with O'Jay Niles, American Textile Manufacturers Association, Charlotte, North Carolina, January 1977).

TABLE 8. RELATIVE AMOUNTS OF DYE USED IN DYEING COTTON FABRICS

Dye type	Amount used, %
Vat	30
Sulfur	20
Naphthol	10
Reactive	15
Disperse	15
Pigment	10

Pigment dyes are not true dyes in that the dye has no affinity for the material. The dye is applied to the fabric and held with resins.

Disperse dyes, which are primarily used on synthetic fibers, are effective on predominantly cotton fabrics blended with synthetics. To accelerate the rate of diffusion of the disperse dye into the polyester fiber, carriers are added to the dye liquor. The most common dye carriers used for polyester fabric dyeing are orthophenylphenol, benzoic acid, salicyclic acid, phenylmethyl carbinol, monochlorobenzene, and biphenyl. Dyeing at atmospheric pressure requires a larger amount of carriers than does the same operation performed under pressure. Dispersing agents, pH control chemicals, and lubricants are other constituents of the dyeing solution [17].

Dyeing with direct dyes is customarily performed batchwise in a dyebath in which the fabric, dye, and appropriate dyeing assistants are properly placed. Dyebath temperature is increased to 94°C to 99°C and maintained for up to one hour. The following after-treatments to direct dyeing result in increased fastness to washing and light:

- Rinsing in a copper sulfate and acetic acid solution.
- Rinsing in a potassium chromate and acetic acid solution.
- Rinsing with a formaldehyde solution.

An important subgroup of direct dyes are developed dyes which are formed through diazotizing an amino group of a direct dye compound and creating a new dye directly on the fabric. The three steps below illustrate the chemistry involved:

Formation of nitrous acid:

$$NaNO_2 + HCl \rightarrow NaCl + HNO_2 \qquad (2)$$

Diazotization:

$$RNH_2 + HNO_2 + HCl \rightarrow RN_2Cl + 2H_2O \qquad (3)$$

where R is an organic radical (i.e., C_5H_7)

$$RN_2Cl + HC_{10}H_6OH \rightarrow RN_2C_{10}H_6OH + HCl \qquad (4)$$

In the developing step, the diazotized dye (RN_2Cl) reacts with the developer β-naphtol ($HC_{10}H_6OH$) and forms the new dye with the formula $RN_2C_{10}H_6OH$. Several other developers also are in common use.

In vat dyeing the insoluble dye is reduced to soluble form using a sodium hydrosulfite and sodium hydroxide solution. Fabric is saturated with reduced vat dye and then reoxidized back to its insoluble, colored form directly on the cloth. Oxidation is caused by treatment in a bath with sodium perborate and steam or sodium dichromate and acetic acid. After reoxidation the fabric is warm washed and then soaped. The final steps are rinsing and drying.

Sulfur dyes are similar to vat dyes. Sodium sulfide or hydrosulfite is utilized to dissolve the dye before exposure to the fabric. A large amount of exhausting agent (salts) must be used for the fabric to efficiently consume the dye. Color is revived by oxidation with sodium perborate, hydrogen peroxide, or potassium dichromate and acetic acid.

Naphthol dyeing involves the same concepts utilized in developed direct dyeing, but in a reverse manner. Fabric is initially impregnated with developer and new dye is formed when the cloth passes through a diazotized dye bath.

Reactive dyes represent the newest class of dyes used in dyeing cotton fabrics. The forces which cause attraction between most dyestuffs and textile fibers are not of the chemical bond nature such as those which hold the atoms of the dye or cellulose molecule together. Instead, reactive dyes link with the cellulose molecule utilizing a chemical bond to produce dyed fabric of exceedingly good wet-fastness qualities [10].

Cellulose contains many hydroxyl groups, which are the sites where the reactive dye will bond under alkaline conditions. Reactive dyes have the characteristic formula, S-R-X, where S represents a solubilizing group, R is a colored organic molecule, and X is a reactive halogen atom [18]. Chemical bonds are formed with the cellulose molecule according to the reaction equation shown below [18]. Reactive dyes can be applied utilizing continuous, pad-batch, or exhaust procedures.

$$\text{S-R-X} + \text{H-O-cellulose} \rightarrow \text{S-R-O-cellulose} + \text{HX} \qquad (5)$$

The continuous process involves the following four steps: padding of the dyestuff, drying, fixation, and final rinses. Dye solution consists of the dye (chloropyrimidine or dichloroquinoxyline types), urea, soda ash, antireducing agent, and a thickener. Drying occurs at 100°C over a time interval of 1 min. The dye is fixed using the thermofix process at a temperature of 166°C for 90 s. The dyed fabric then encounters final hot and cold water baths and a detergent rinse which removes excess materials.

The pad-batch method of dyeing cotton fabrics with reactive dyes is similar to the continuous method with an exception in the fixation step. Vinyl sulfone-type reactive dyes are utilized in this method, and fixation of the dye occurs over a 16-hr span at 20°C to 30°C. Following fixation, soaping and rinsing operations cleanse the fabric of process chemicals.

Chlorotriazine-type reactive dyes are used in the exhaust method of dyeing cotton fabrics. The process involves adding common salt gradually to the dyebath over a 40-min period, followed by addition of soda ash. The acquired alkalinity of the dyebath initiates the fixation step. The final operations are rinses and soaping [10].

Drying

Following the dyeing of a fabric, the cloth is dried regardless of the type of dye used. A typical piece of fabric is dried three times on the average in the finishing mill. Drying operations occur after bleaching, dyeing or printing, and finishing. Drying is conducted at 100°C to 115°C for cotton fabrics and utilizes tenter frames or can-drying equipment.

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[18] Postman, W. Dyeing: Theory and Practice. National Aniline Division, Allied Chemicals, New York, New York, 1970. 40 pp.

Tentering, a forced air drying technique, consists of two endless chains riding in rugged rails. The chains are constructed with clips or pins, which clasp the selvage of the fabric and transport it into a heated enclosure where a steady stream of hot air removes any moisture. Clip frames are usually used for drying cotton fabrics, and the entire process operates continuously [10].

Can-drying, a direct contact drying technique, involves drying of the fabric on rollers or cans which are heated using steam.

Printing

Roller printing and screen printing are two major methods of printing colored designs or patterns on cotton broadwoven fabric. A total of 394 roller printing machines were operating in textile finishing mills in 1973 [19]. Of this total, 165 were primarily utilized in the printing of cotton fabrics. Figure 4 illustrates the essence of a four-color, roller printing machine. The large drum (pressure bowl) rotates the fabric as the engraved rolls (rolls A, B, C, and D) print a pattern. The printing rolls are constantly padded with dye paste from the nearby color boxes. After printing the dye (dye paste) is fixed on the fabric in an operation termed aging. In this process, the cloth is treated with steam from 1 min to 10 min at 88°C to 100°C. Fixation is also achieved using steam, an operation that is similar to aging.

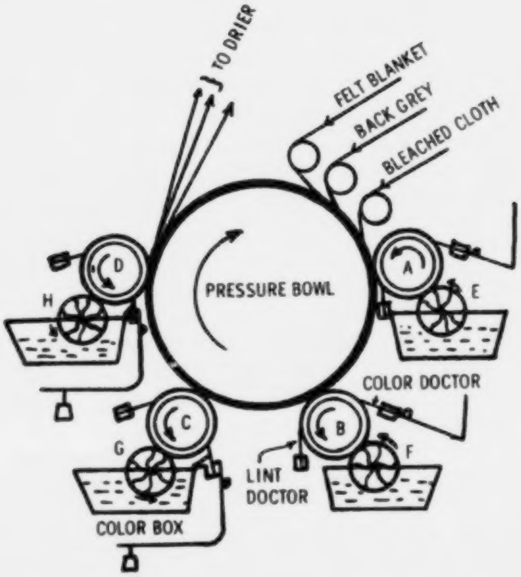

Figure 4. Four-color, roller printing machine [11].

Treatment time in fixation by steaming is longer (1/2 hr to 2 hr) and hotter (100°C) than that used in ordinary aging. In either case, the key function is to permit the dye to penetrate the fabric and react with chemicals in the dyepaste to yield high-quality fastness characteristics. Final printing operations include washing, rinsing, and drying [10].

Printing pastes are composed generally of a dye, a thickener, a hygroscopic substance, water, and other dyeing assistants. The most common hygroscopic substance used is glycerol. Common thickening agents used are starches, British gum, and vegetable gums.

Screen printing can be performed utilizing a flat screen or rotary screen. In 1973, there were 515 screen printing machines in the United States of which 208 were used primarily to process cotton broadwoven fabric [19].

Flat screen printing is performed manually or using electronically controlled automatic machines. Hand screen printing is a lengthy operation and is limited to fabric lengths of 54 m. Fabric to be printed is spread out on a long table. The desired pattern is obtained using prepared screens which are laid on the fabric and covered with dyepaste, which is spread uniformly with a squeegee. A pattern appears after the screen is removed. The automatic method screen-prints fabric at a rate up to 411 m/hr. In this method, the hand process is merely mechanized. One exception is the use of an adhesive to coat the back of the cloth. The adhesive causes the cloth to adhere to a conveyor belt that serves as a tabletop during the operation [6]. The last operation in the printing range is drying.

Rotary screen printing combines features of roller and flat screen printing. This printing machine utilizes cylindrical screens in applying designs to the cloth. Fabric is printed as the cloth rides a conveyor printing blanket. Adhesion to the blanket is accomplished using an adhesive or a mechanical gripping device. Dyepaste is forced through the cloth as it travels through the machine at speeds up to 91 m/min. Finally, the cloth is dried.

Singeing

When woven cotton fabric is received at the finishing mill, its surface has a fuzzy or hairy texture due to loose fibers. The singeing operation burns off the fuzz and a smooth finish is imparted to the surface. Three types of singers in use are plate, roller, and gas [10]. The first two methods involve passing the fabric over heated plates or a heated roller. Gas singeing, the most predominant type, entails the passage of the cloth over a gas flame at a high speed (275 m/min) [10]. Following singeing, the fabric travels through a water box to extinguish any sparks.

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[19] 1972 Census of Manufacturers. Textile Machinery in Place. Special Report Series. MC72(SR)-5, U.S. Department of Commerce, Washington, D.C., August 1973. 11 pp.

Special Finishing

Special finishing operations endow the fabric with a particular appearance, surface texture, or behavior characteristics. Several special finishing operations were mentioned earlier but a more complete list along with the relative amounts of fabric treated in each method is presented in Table 9 (personal communication with O'Jay Niles, American Textile Manufacturers Institute, Charlotte, North Carolina, August 1977). These finishes generally do not depend on the type of fiber composing the fabric. Most fabrics receive one or more of these finishes, as dictated by the requirements to meet the consumer's needs.

TABLE 9. SPECIAL FINISHES APPLIED TO COTTON AND SYNTHETIC TEXTILE FABRICS [6]

Type of finish [6]	Amount of fabric treated, %[a] Cotton	Amount of fabric treated, %[a] Polyester and blends	Type of operation
Compressive shrinkage	20	0	Mechanical
Shape-retentive finishes	30	0	Coating
Water-repellent finishes	20	5	Coating
Flameproofing or retardancy	20	10	Coating
Stain-repellent finishes	30	30	Coating
Antistatic finishes	0	5	Chemical treatment
Germicidal finishes[b]	1	2	Chemical treatment
Fungicidal finishes[b]	2	0	Chemical treatment
Stiffening	5	0	Chemical treatment
Absorbent finishes	1	2	Chemical treatment
Soil release finishes	5	10	Chemical treatment
Moireing	1	1	Chemical treatment
Embossing	0	1	Mechanical
Calendaring	10	10	Mechanical

[a] Personal communication, O'Jay Niles, August 1977.

[b] Antibacterial finishes could replace germicidal and fungicidal finishes.

Much developmental work has been conducted in recent years concerning the composition and application of chemical resin or organic finishes. The general sequence shown below is followed in chemically treating the fabric [6]:

- padding the fabric with the chemical finish
- drying the fabric
- curing or setting the finish
- rinsing in order to remove excess material

Curing involves exposure of the treated fabric to temperatures in excess of 205°C [20].

Due to the large number of finishing treatments, only the operations performed to a high degree (as derived from Table 9) are described in this report.

Compressive Shrinkage--

Fibers are in a state of tension while undergoing weaving. Fibers tend to return to their natural unstretched state when exposed to wet operations in the finishing plant. Although a substantial amount of shrinkage occurs during these operations, the fabric will likely experience further shrinkage when washed by the consumer. Shrinkage is a problem generally characteristic of cellulosic fabrics since most synthetic fiber fabrics are dimensionally stable due to the heat setting operation [6].

To maximize the shrinkage in the finishing operations, the fabric is exposed to a special shrinking operation, such as compressive shrinkage, wherein tension is exerted on the fabric when it is damp.

The initial step in the sanforizing operation is to determine the normal shrinkage that the fabric will experience utilizing a standard wash or shrinkage test. The compressive shrinkage machine, shown in Figure 5 is preset to shrink the cloth this predetermined amount. As the material enters the range it encounters a series of tension bars, guide rolls, and feed-control rolls. The feed-control rolls indirectly control the amount of shrinkage that the fabric experiences by regulating the rate at which material enters the range. From these rolls a steam housing unit dampens the fabric so that the fiber swells and becomes soft. The next unit, the skyer, allows the moisture absorbed to fully penetrate the fabric. The segment of the machine where the actual shrinkage occurs is illustrated in Figure 6. In this unit the fabric adheres to the stretched surface of the felt blanket as a result of the reversal of curvature in its path. Fabric

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[20] Mathews, J. C., G. E. Weant III, and J. J. Kearney. Screening Study on the Justification of Developing New Source Performance Standards for Various Processing Operations. Contract 68-02-0607-11, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, August 1974. 106 pp.

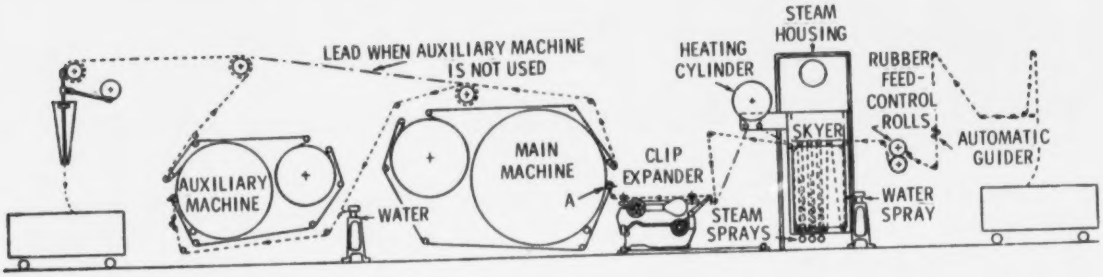
LEAD WHEN AUXILIARY MACHINE IS NOT USED
STEAM HOUSING
HEATING CYLINDER
RUBBER FEED-CONTROL ROLLS
SKYER
AUTOMATIC GUIDER
AUXILIARY MACHINE
MAIN MACHINE
CLIP EXPANDER
A
WATER
STEAM SPRAYS
WATER SPRAY

Figure 5. Sanforizing range [11].

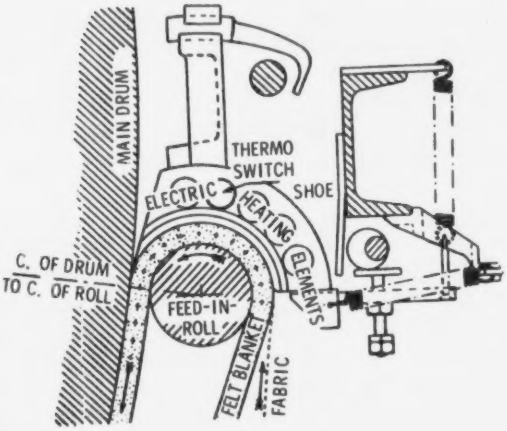
MAIN DRUM
THERMO SWITCH
SHOE
ELECTRIC HEATING ELEMENTS
C. OF DRUM TO C. OF ROLL
FEED-IN-ROLL
FELT BLANKET
FABRIC

Figure 6. Main belt shrinker [11].

then shrinks uniformly as a consequence of its adhesion to the outer surface of the blanket [10].

Overall machine operation creates a lengthwise tension in the material, causing it to decrease in width (narrowing). To remedy this situation, a small tenter frame (clip expander) stretches the cloth to the required width. A smooth finish is automatically imparted on the surface of the cloth that is adjacent to the main heated cylinder. If this finish is desired on both sides, the fabric travels through the auxiliary machine.

Some fabrics are treated with resins to control shrinkage. The typical resin used is urea-formaldehyde. The operation consists of padding the fabric with the resin, followed by drying and heat curing [20].

Shape-Retentive and Permanent Press Finishes--
Cellulosic cotton fibers lack the resilience properties of wool, silk, or manmade fibers. To make cotton fabrics desirable to the consumer, who demands easily cared-for garments, wrinkle-resistant finishes were developed. Later, a new breed of cotton fabric known as permanent press finished was produced.

Compounds used to obtain wrinkle-resistant finishes are urea formaldehyde resin, melamine formaldehyde resin, or dimethylolethylene urea resin. These resin compounds combine chemically with the cotton fiber in a process known as cross-linking. Adjacent molecular chains of cellulose in the fiber are bonded together in a way that prohibits intermolecular slippage. Vinyl sulfones and epichlorohydrin are in limited use as wrinkle-resistant agents. Application of these compounds involves padding the broadwoven cloth with a solution containing the finishing resin, an appropriate catalyst (zinc chloride) softening agents, and wetting agents. Treated fabric is dryed on a tenter frame at a temperature below 94°C. Curing is then performed at temperatures above 125°C. Following curing, two soapings and two additional rinses are applied to remove any excess catalyst or resin from the material [6, 10].

Permanent press finishes were developed as a remedy to the garment manufacturers' problem encountered in shaping wrinkle-resistant goods. Several permanent press finishes are used commercially, all of which are designated by trade names. The first commercially available finish of this type was Koratron, developed in 1963, in which the fabric was treated with imidazolidone at the finishing plant. After application, the cloth is dried at low temperatures to prohibit the setting reaction of the imidazoli done. Treated material is sent to the garment manufacturer, who cuts and sews the cloth. Finished garmets are hung on special hangers and passed through a 160°C curing oven. This final curing operation, performed at the garment manufacturing plant, permanently sets the shape given to the cloth on pressing machines.

Water Resistant Finishes--
Two types of water resistant finishes are available. One consists of a waterproof finish in which an impenetrable water-resistant film coats the surface of the fabric. When individual fibers are subject to coating with water-resistant compounds, the finish is termed repellent. Water resisting finishes are also categorized as durable or nondurable. A durable water repellent finish is defined as one for which the repellency will withstand laundering and drycleaning for the entire life of the garment.

Fabrics that are treated for water resistance but that cannot withstand ordinary cleaning operations are termed nondurable.

Durable water repellents include such compounds as stearamido methyl pyridinium chloride, stearoxy methyl pyridinium chloride, combinations of melamine resins and stearamides, and silicone compounds. These compounds are applied in a continuous process consisting of the following operations: padding, drying, curing, and washing. Figure 7 shows a possible arrangement for applying water repellent finishes [6, 10].

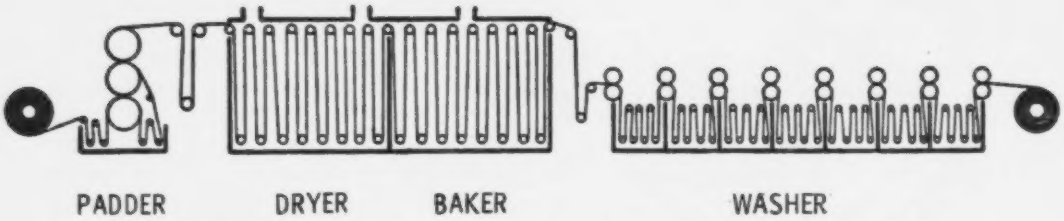

Figure 7. Continuous unit for applying durable water repellent finishes [10].

During the drying and curing operations, substituted pyridinium chloride compounds decompose as a result of high process temperatures. Drying is performed at temperatures ranging from 110°C to 150°C. Curing is conducted at temperatures ranging from 116°C to 205°C. The decomposition fixes a $C_{17}H_{35}$ radical on the cotton fiber. Pyridine and hydrochloric acid are decomposition products. Air emissions from the drying and curing operations contain these two species and have a disagreeable odor (pyridine). Washing is usually performed in an open-width box washer consisting of seven or eight boxes. The first two boxes contain detergent and alkali to neutralize the acid decomposition products. The remaining boxes contain hot and cold water. After final washing, the fabric is dried.

Nondurable water repellent finishes are based on a paraffin wax-aluminum acetate emulsion. Zirconium salts are being substituted for aluminum in some cases, since a higher quality finish results. This type of finish is applied on a continuous manner utilizing simple pad and dry operations. Drying of the treated fabric is performed at 102°C to 110°C. At these temperatures, the wax used melts, resulting in better film coverage.

Waterproofing a fabric involves coating it with a compound that is totally insoluble in water. Most waterproofing substances in use today are vinyl resins. The Koroseal waterproofing process entails coating of the surface of the cloth with polyvinyl chloride.

Other Finishes--

Most other special finishes consist of either a mechanical, resin, or chemical treatment of the fabric. The finishes covered above consist of the major resin and chemical treatments that would be the largest contributors to the emission streams.

MATERIALS FLOW

Because many chemicals are used by the textile finishing industry in a variety of processes, it would be very difficult to evaluate the mass emissions from each chemical used, especially since many materials are sparsely used. However, the finishing industry is subject to rapid changes in chemical usage and an overall look at the materials flow is of value. Based upon a review of literature sources, the chemicals associated with each unit operation were deduced. These conclusions were reviewed with the ATMI air subcommittee (November 1976, Fred Rainey, Chairman) to represent current practice in industry.

A list of major chemicals known to be used in the cotton finishing industry is given in Table 10 (next page). In the table, these chemicals are classified by the major processing steps involved as discussed in the Process Description section of this document. The constituents of typical baths are provided where applicable. For each process step, the most predominant methods are listed first. In addition to the chemicals listed, solvents are widely used in the dyeing, printing, and special finishing operations.

Chemical usage for polyester and cotton/polyester blends finishing is provided in Table 11 in the same manner as shown for cotton finishing.

Special Finishes

Special finishes and their related chemical usage are given in Table 12 [16].

TABLE 10. CHEMICALS ASSOCIATED WITH TYPICAL PROCESSES USED IN COTTON TEXTILE FINISHING PLANTS

Process	Methods	Typical bath constituents
Desizing	Sulfuric acid	Sulfuric acid solution
	Enzymes	Commercial enzyme, NaCl, penetrant
	Detergents	
Scouring	Caustic soda	Caustic soda, trisodium phosphate, silicate of soda, detergent, tetrasodium phosphate
Bleaching	Hydrogen peroxide	Hydrogen peroxide, sodium silicate, caustic soda, soda ash, wetting agent
	Sodium hypochlorite	Sodium silicate, sodium peroxide, sulphuric acid, sodium bicarbonate
Mercerizing	Caustic soda	Caustic soda, penetrants (usually creosols)
Dyeing	Direct	Soluble dye, sodium chloride, acetic acid, copper sulfate
	Sulfur	Dye, sodium sulfide, sodium hydrosulfite, sodium chloride, sodium perborate, hydrosulfite, sodium chloride, sodium perborate, hydrogen peroxide
	Vat	Insoluble dye, sodium hydrosulfite, caustic soda, sodium perborate
	Reactive	Dye, sodium chloride, soda ash, trisodium phosphate
	Naphthol	Dye, caustic soda, sodium chloride, sodium nitrate, β-naphthol
	Aniline black	Aniline hydrochloride, sodium chlorate, copper sulfate
Printing	Fiber reactive	Dye, urea, sodium carbonate, thickening agents (possibly hydrocarbon emulsion)
	Vats	Dye, alkali, reducing agent, thickening agent
	Pigments	Pigment, resin binder, latex, emulsifier

TABLE 11. CHEMICALS ASSOCIATED WITH TYPICAL PROCESSES USED IN POLYESTER TEXTILE FINISHING PLANTS

Process	Methods	Typical bath constituents
Desizing	Sulfuric acid	
	Enzymes	Enzyme, sodium chloride, penetrant
Scouring	Synthetic detergent	Synthetic detergent, soda ash
	Soap	
	Solvent	Perchloroethylene
Bleaching	Hydrogen peroxide	Hydrogen peroxide, wetting agent, pH stabilizer
	Peracetic acid	Sodium hexametaphosphate, peracetic acid, wetting agent
Dyeing	Disperse	Dye, diphenyl, acetic acid, soap
	Azoic	Dye, oleyl sodium sulfate, caustic soda, sodium hydrosulfite, cetyl trimethyl ammonium bromide, β-oxynaphthoic acid, sodium nitrite, hydrochloric acid
	Vat	Insoluble dye, oleyl sodium sulfate
Printing	Disperse	Dye, dispersing agent, carrier (p-phenylphenol), sodium nitrite, hydrochloric acid
	Basic	Dye, tannic acid, organic acid, thickeners

TABLE 12. CHEMICALS RELATED TO SPECIAL FINISHING IN TEXTILE FINISHING PLANTS [10]

Process	Methods	Typical bath constituents
Fire retardant finishing	Nondurable	Borax, boric acid, diammonium phosphate, sodium phosphate
Shape-retentive finishing	Dimethylol dihydroxyl ethylene urea (DMDHEV) Carbamates	DMDHEV, surfactant, softener, catalyst
Stiffening	Polyvinyl acetate Acrylics Starches	
Softening	Anionic softener Cationic softener	Sulfonated tallows
Water and soil repellent finishing	Fluorochemicals	Fluorochemical, extender, hand modifier, thermosetting resin
	Silicones Pyridinium salts	
Soil release finishing	Fluorochemicals	
Mildewproofing	Salicylanilide Phenyl mercurials bis(2-hydroxy-5-chlorphenyl) methane	
Antistatic finishing	Cationics	Quarternary ammonium derivatives
	Anionics Nonionics Amphoterics	

SECTION 4

AIR EMISSIONS

SOURCES AND NATURE

In a typical woven fabric finishing plant air emissions arise from a number of sources. These sources include: process emissions, room vents which exhaust fugitive emissions from processing equipment, leaks, oil spills, nonprocess related point source emissions from chemical and fuel storage tank vents and ancillary equipment such as fossil fuel fired steam generators, and fugitive emissions from wastewater treatment systems. The scope of this project addresses air emissions from process unit operations.

Woven fabric finishing unit operations which are vented to the atmosphere include singeing, heat setting, scouring, desizing, washing, bleaching, mercerizing, drying, thermosol dyeing, open beck dyeing, printing, and the application of special finishes which involves drying or curing of chemicals. As emphasized in Section 3, each manufacturing facility uses different combinations of unit operations and raw materials, therefore, each plant may use some or all of these unit processes. Emissions from these operations are exhausted to the atmosphere via vents from the dryers following each operation and exhaust hoods placed collectively over several processes which vent fugitive emissions.

General factors which affect the composition and quantity of emissions include characteristics of particular chemicals used, temperature at which the process is conducted, order in which processing is carried out, and extent to which emissions controls are applied. Chemicals used for a particular process, those added during prior processing steps, plus any reaction products between these chemicals are all potential emission species. If high temperatures (>50°C) are used, then thermal degradation products of the above species may also be present.

EMISSIONS DATA

There are little data in the literature characterizing airborne emissions from woven fabric finishing operations. Much of what is available is of limited utility because background information such as testing and analytical procedures used, operating parameters, etc. are not reported. This type of information is essential in establishing the reliability of reported data and in calculating emission factors.

In order to evaluate the potential environmental impact of this industry a sampling and analytical program was designed to provide detailed analyses of the organic and inorganic components of the stack gas streams. Processes determined to have the largest volume and greatest potential for hydrocarbon emissions were sampled at four woven fabric finishing plants. The plants selected reflected the range in age of equipment, quantities of fabric handled, and the types of process operations that are typical of this industry.

Three emission sources at each plant site were sampled with a Source Assessment Sampling System (SASS) train. This system collects particulate matter and gaseous pollutants semi-isokinetically for both organic and inorganic analyses. Samples from the SASS train were analyzed for trace metals and organic species. These three points and additional emission points at each site were sampled for total nonmethane hydrocarbon and C_1 through C_6 hydrocarbon emissions using a field portable gas chromatograph with a flame ionization detector. Detailed descriptions of the sampling and analytical procedures used are presented in Appendix A.

Processes sampled with the SASS train included heat setting, Thermosol dyeing, finishing on a tenter frame, and curing of finished goods in a curing oven. Average emission factors were determined for individual emission species from each of the processes sampled are shown in Tables 13 through 16. Average total nonmethane hydrocarbon emission factors for a number of additional processes are shown in Table 17. Additional emissions data including emission factors determined for each piece of equipment sampled, physical characteristics of the stack gas streams, and process data (type of fabric, speed of fabric, chemicals used, etc.) are given in Appendix B.

One notable feature of the data in Tables 13 through 17 is the range in emission factors observed for similar unit operations at different plants. This underscores the fact that there are unlimited possibilities in the combination of unit operations used, order of processing, and chemicals used in the woven fabric finishing industry to produce a fabric with the specific qualities desired by the customer.

Close examination of the emission species and analytical procedures reflect several key items. For example, the XAD-II resin in the SASS train was extracted with methylene chloride. Therefore, the three species, methyl myristate, palmitate, and stearate, actually appear in the stack as the sodium soaps which are nontoxic. This conclusion is further supported by the larger amounts of sodium in the stack gas. Similarly, the long chained methyl esters reported, actually appear in the stack as long chained organic alcohols, such as polyvinyl alcohol, or starches.

TABLE 13. EMISSION FACTORS DETERMINED FOR A HEAT SETTING OPERATION

Emission species	Emission factor, mg/kg of fabric
Particulate matter	294
Organic compounds:	
Diethyl phthalate	0.25
Dipropyl phthalate	0.33
Dibutyl phthalate	0.41
Di-C_8-alkyl phthalate	1.3
Methyl palmitate	4.9
Methyl stearate	12
Methyl-C_{14}-ester	0.0065
Methyl-C_{17}-ester	0.52
Aliphatics (C_{12}-C_{34})	150
Trace elements:	
Aluminum	0.020
Antimony	0.057
Barium	0.0036
Beryllium	0.0065
Boron	0.0025
Cadmium	0.0046
Calcium	0.090
Chromium	0.017
Cobalt	0.017
Copper	0.0061
Iron	0.020
Lead	0.093
Magnesium	0.038
Magnesium	0.016
Manganese	0.011
Molybdenum	0.24
Nickel	0.062
Phosphorus	0.095
Silver	0.013
Sodium	520
Strontium	0.0034
Tin	0.81
Titanium	0.00040
Vanadium	0.0021
Zinc	0.074

TABLE 14. AVERAGE EMISSION FACTORS FOR THERMOSOL DYE RANGES

Emission species	Number of plants at which species was identified	Range of emission factor values, mg/kg of fabric	Average emission factor, mg/kg of fabric
Particulate matter	3	140 to 410	230
Organic compounds:			
2-ethylhexanol	1	-	2.1
$C_3/C_4/C_5$-alkylbenzenes	2	1.7 to 3.7	2.7
Ethyl styrene	1	-	0.54
Dichlorobenzenes	1	-	1.6
Trichlorobenzenes	1	-	0.68
Napthalene	2	0.45 to 1.6	1.0
Methyl naphthalenes	2	0.069 to 6.4	3.2
Dimethyl naphthalenes	2	0.095 to 3.7	1.9
C_3 above napthalenes	1	-	0.016
Butyl benzoate	1	-	10.7
Biphenyl	2	0.090 to 6.5	3.3
Dimethyl phthalate	2	1.4 to 2.3	1.9
Diethyl phthalate	2	0.0024 to 0.0066	0.0045
Dipropyl phthalate	2	0.055 to 0.11	0.083
Dibutyl phthalate	2	0.051 to 0.77	0.41
Di-C_8-alkyl phthalate	3	0.021 to 2.2	0.79
Bromochlorobenzene	1	-	0.13
Bromodinitrobenzene	3	0.37 to 6.4	3.3
Dichloronitroaniline	1	-	0.60
Bromodinitroaniline	1	-	1.2
Anthraquinone	2	0.10 to 19	9.6
Aminoanthraquinone	1	-	2.5
Methyl-C_{11}-ester	1	-	0.40
Methyl-C_{12}-ester	1	-	0.65
Methyl-C_{13}-ester	1	-	0.53
Methyl-C_{14}-ester	1	-	3.6
Methyl-C_{15}-ester	1	-	1.8
Methyl-C_{16}-ester	1	-	4.0
Methyl-C_{19}-ester	1	-	0.88
Methyl-C_{20}-ester	1	-	0.48
Methyl myristate	2	0.094 to 0.48	0.29
Methyl palmitate	3	7.8 to 18	13
Methyl stearate	3	16 to 20	18
Palmitic acid	2	1.6 to 180	91
Diphenyl ethane	1	-	0.29
Ethyl-phenyl-phenyl-ethane	1	-	0.48
Aliphatics	3	8.6 to 45	22
Trace elements:			
Aluminum	3	0.069 to 0.19	0.11
Antimony	2	0.045 to 0.078	0.062
Barium	3	0.0010 to 0.095	0.039
Beryllium	1	-	0.00019
Boron	3	0.038 to 0.15	0.077
Cadmium	3	0.00028 to 0.0039	0.0017
Calcium	3	0.31 to 2.2	1.1
Chromium	3	0.073 to 0.22	0.12
Cobalt	3	0.0030 to 0.0069	0.0051
Copper	3	0.030 to 12	4.0
Iron	3	0.25 to 1.4	0.67
Lead	3	0.016 to 0.056	0.038
Magnesium	3	0.057 to 1.9	0.72
Manganese	3	0.017 to 0.045	0.029
Molybdenum	3	0.0064 to 0.050	0.030
Nickel	2	0.071 to 0.11	0.091
Phosphorus	3	0.070 to 0.29	0.17
Silicon	2	0.49 to 8.5	4.5
Silver	2	0.0015 to 1.2	0.60
Sodium	3	360 to 5,300	2,000
Strontium	3	0.0028 to 0.0031	0.0029
Tin	3	0.072 to 0.66	0.34
Titanium	2	0.00088 to 0.0030	0.0019
Vanadium	2	0.00015 to 0.0061	0.0031
Zinc	3	0.076 to 0.12	0.099

TABLE 15. AVERAGE EMISSION FACTORS FOR RESIN FINISHING TENTER FRAMES

Emission species	Number of plants at which species was identified	Range of emission factor values, mg/kg of fabric	Average emission factor mg/kg of fabric
Particulate matter	4	32 to 1,300	560
Organic compounds:			
Dichlorobenzenes	1	-	16
Trichlorobenzenes	1	-	380
Tetrachlorobenzenes	1	-	17
$C_3/C_4/C_5$ alkylbenzenes	2	3.7 to 3.9	3.8
Ethyl styrene	2	1.4 to 6.4	3.9
Divinyl benzene	2	0.14 to 0.71	0.43
Naphthalene	2	1.5 to 1.8	1.7
Methyl napthalenes	3	0.087 to 26	8.8
Dimethyl napthalenes	2	0.12 to 32	16
C_3^+ above napthalenes	1	-	11
Benzoic acid	1	-	7.1
Butyl benzoate	3	0.14 to 490	320
Biphenyl	3	0.21 to 150	50
Methyl biphenyl	1	-	2.3
Dimethyl phthalate	3	0.85 to 390	130
Diethyl phthalate	1	-	0.34
Dipropyl phthalate	2	0.0055 to 0.037	0.021
Dibutyl phthalate	3	0.54 to 2.9	1.4
Di-C_8-alkyl phthalate	4	0.036 to 1.6	0.64
C_9-phenols	1	-	0.39
t-butyl-hydroxyanisole	1	-	0.028
Bromodinitrobenzene	2	1.1 to 40	21
Anthraquinone	2	1.5 to 4.6	3.1
Aminoanthraquinone	1	-	0.44
Methyl dodecanoate	1	-	3.4
Methyl myristate	2	0.7 to 1.5	1.1
Methyl palmitate	4	0.18 to 10	4.3
Methyl stearate	4	0.33 to 14	5.3
Methyl-C_{17}-esters	1	-	0.55
Dichloronitroaniline	1	-	3.3
Diphenyl ethane	1	-	1.4
Ethyl-phenyl-phenyl-ethane	1	-	2.3
Di(ethyl phenyl)ethane	1	-	0.35
Octamethylcyclotetrasiloxane	1	-	2.6
Siloxane (dominant ion 267)	1	-	0.95

TABLE 15 (continued)

Emission species	Number of plants at which species was identified	Range of emission factor values, mg/kg of fabric	Average emission factor, mg/kg of fabric
Organic compounds (continued):			
Siloxane (dominant ion 341)	1	-	0.45
Oxygenates (e.g., alcohols, alcoholic ethers, etc., estimated C_{12} and above)	1	-	9.9
Unknown "245" ion	1	-	3.1
Unknown "243" ion	1	-	4.8
Unknown "241" ion	1	-	6.0
Unknown "240" ion	1	-	2.2
Unknown "269" ion	1	-	0.29
Unknown "239" ion	1	-	2.4
Unknown "85" ion	1	-	3.7
Aliphatics	4	19 to 260	140
Trace elements:			
Aluminum	4	0.037 to 3.8	1.3
Antimony	2	0.42 to 0.84	0.63
Barium	4	0.0097 to 0.067	0.040
Beryllium	1	-	0.0096
Boron	4	0.045 to 0.094	0.075
Cadmium	4	0.0058 to 0.040	0.019
Calcium	4	0.091 to 2.4	0.90
Chromium	4	0.14 to 0.81	0.53
Cobalt	4	0.011 to 0.25	0.086
Copper	4	0.053 to 0.92	0.26
Iron	4	0.84 to 4.5	2.5
Lead	4	0.071 to 0.74	0.46
Magnesium	4	0.18 to 1.4	0.63
Manganese	4	0.020 to 0.19	0.083
Molybdenum	3	0.018 to 0.76	0.43
Nickel	4	0.18 to 0.60	0.41
Phosphorus	4	0.038 to 5.0	1.8
Silicon	3	0.80 to 15	9.9
Silver	3	0.00017 to 0.56	0.19
Sodium	4	60 to 1,080	440
Strontium	4	0.00096 to 0.0084	0.0046
Tin	4	0.40 to 3.1	1.9
Vanadium	1	-	0.24
Zinc	4	0.15 to 1.1	0.63

TABLE 16. AVERAGE EMISSION FACTORS FOR RESIN FINISH CURING OVENS

Emission species	Number of plants at which species was identified	Range of emission factor values, mg/kg of fabric	Average emission factor, mg/kg of fabric
Particulate matter	3	31 to 340	160
Organic compounds:			
$C_3/C_4/C_5$ alkyl benzenes	3	1.1 to 69	24
Ethyl styrene	2	3.1 to 6.1	4.6
Divinyl benzene	1	-	0.64
Dichlorobenzenes	1	-	0.064
Trichlorobenzenes	1	-	0.064
Napthalene	3	0.63 to 5.5	3.0
Methyl napthalenes	3	0.26 to 2.1	1.0
Dimethyl napthalenes	2	0.51 to 0.94	0.73
C_3 and above napthalenes	1	-	0.35
Benzoic acid	1	-	130
Butyl benzoate	3	4.9 to 1,800	600
Biphenyl	3	2.1 to 50	3.3
Methyl biphenyl	1	-	8.3
Dimethyl phthalate	3	0.64 to 60	21
Diethyl phthalate	1	-	0.0022
Dipropyl phthalate	1	-	0.012
Dibutyl phthalate	3	0.053 to 3.8	1.9
Di-C_8-alkyl phthalate	3	0.013 to 1.0	0.46
C_8 phenols	1	-	0.92
C_9 phenols	1	-	4.1
Dimethyl alkyl amines	1	-	46
Bromodinitrobenzene	2	0.32 to 11	5.7
Dichloronitroaniline	2	0.13 to 9.6	4.9
Anthraquinone	2	0.069 to 13	6.5
Methyl dodecanoate	1	-	0.010
Methyl myristate	2	0.039 to 3.7	1.9
Methyl palmitate	3	0.036 to 72	24
Methyl stearate	3	0.078 to 92	31
Palmitic acid	1	-	42
Diphenyl ethane	1	-	3.1
Ethyl-phenyl-phenyl-ethane	1	-	4.4
Unknown "245" ion	1	-	2.4
Unknown "243" ion	1	-	2.0
Unknown "241" ion	1	-	1.4
Unknown "240" ion	1	-	4.1
Unknown "269" ion	1	-	0.43
Unknown "239" ion	1	-	5.6
Unknown "85" ion	1	-	6.4
Oxygenates (e.g., alcohols, alcoholic ethers, etc., estimated C_{12}^{+} above)	1	-	16
Aliphatics	3	29 to 134	69
Trace elements:			
Aluminum	1	-	0.018
Antimony	1	-	0.088
Barium	3	0.00064 to 0.053	0.019
Beryllium	1	-	0.0043
Boron	3	0.0047 to 0.099	0.037
Cadmium	2	0.016 to 0.041	0.029
Calcium	3	1.1 to 7.9	4.1
Chromium	3	0.012 to 0.72	0.25
Cobalt	3	0.00015 to 0.038	0.018
Copper	3	0.0094 to 1.3	0.50
Iron	3	0.072 to 2.6	1.1
Lead	3	0.0067 to 0.52	0.18
Magnesium	3	0.22 to 4.4	2.1
Manganese	3	0.0023 to 0.12	0.074
Molybdenum	1	-	0.067
Nickel	2	0.0072 to 0.14	0.074
Phosphorus	3	0.073 to 1.0	0.39
Silicon	3	150 to 440	270
Strontium	3	0.0016 to 0.0058	0.0035
Tin	3	0.37 to 1.1	0.78
Titanium	1	-	0.0026
Zinc	3	0.068 to 1.3	0.76

TABLE 17. TOTAL NONMETHANE HYDROCARBON EMISSIONS

Operation or equipment sampled	Number sampled	Range of emission factors, mg/kg	Average emission factor, mg/kg
Heat set	2[a]	610 to 680	645
Thermosol dye range	4	57 to 1,300	480
Resin finishing on a tenter frame	9	67 to 15,100	3,160
Drying on a tenter frame	2[a]	6,350 to 17,700	12,000
Curing oven	4	240 to 9,300	2,600
Continuous dyeing in a washbox	1	-	440

[a] Both units located at one plant.

ENVIRONMENTAL EFFECTS

Air emissions released during the finishing of woven fabrics may have an adverse effect on the quality of air, water, and land resources; vegetation, property, and/or animal and human health. Emissions from finishing operations enter the atmosphere as a concentrated plume. Primary impacts result from direct contact of the receptor with this plume. The magnitude of the impact depends on the chemical composition and the concentration of emission species at the point of contact. This is in turn dependent on a variety of factors including the particular process, specific chemicals used, height of emission release, atmospheric conditions, distance from the source, and other factors. Secondary impacts can occur after dispersion of the plume throughout the environment. While the fate and environmental effects of many trace pollutants are not known, those of the major species are well documented [21-23].

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[21] Air Pollution, Volume I: Air Pollution and Its Affects, Second Edition, A. C. Stern, ed., Academic Press, New York, New York, 1968. 694 pp.

[22] Leighton, P. A. Photochemistry of Air Pollution. Academic Press, New York, New York, 1961. 300 pp.

[23] Seinfeld, J. H. Air Pollution - Physical and Chemical Fundamentals. McGraw-Hill Book Company, New York, New York, 1975. 523 pp.

This segment of the report evaluates the potential environmental effects due to air emissions. The focus is on emissions from key unit operations because each textile mill operates the finishing processes differently. The evaluation is performed for an average-size woven fabric finishing plant, defined by the EPA to produce 11,400 Mg/yr of products [2, 3].

Source Severity

The potential environmental effects of air emissions from a point source can be measured in several ways. The method used here is to determine the maximum ground level concentration of each emission species downwind from the average plant and compare this value to the primary ambient air quality standard for criteria emissions [24] or to a reduced threshold limit value (TLV) [25] for the noncriteria emission species.

The comparison is called source severity, S_a, and is defined as

$$S_a = \frac{\bar{X}_{max}}{F} \qquad (6)$$

where $\bar{X}_{max}$ = maximum time-averaged ground level concentration for each emission species, g/m^3

F = primary ambient air quality standard for criteria pollutants (particulate matter, sulfur oxides, nitrogen oxides, carbon monoxide, and hydrocarbons), g/m^3

or

$$F = TLV \times 8/24 \times 1/100, \text{ for noncriteria emission species, } g/m^3 \qquad (7)$$

where TLV = threshold limit value for each species, g/m^3

8/24 = correction factor to adjust the TLV to a 24-hr exposure level

1/100 = safety factor

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[24] Code of Federal Regulations, Title 42 - Public Health, Chapter IV - Environmental Protection Agency, Part 410 - National Primary and Secondary Ambient Air Quality Standards, April 28, 1971. 16 pp.

[25] TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1979. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1979. 94 pp.

The value of $\bar{\chi}_{max}$ for an average source is calculated from

$$\bar{\chi}_{max} = \chi_{max} \; \frac{t_o}{t}^{\,0.17} \tag{8}$$

where $\chi_{max} = \frac{2\,Q}{(\pi e u H^2)}$ for elevated point sources (9)

and

Q = emission rate, g/s
π = 3.14
$\underline{e}$ = 2.72
$\bar{u}$ = average wind speed, 4.5 m/s (national average)
t_o = short-term averaging time, 3 min
t = averaging time, min
H = height of emission release, m

The equation for $\bar{\chi}_{max}$ (Equation 8) is derived from the general plume dispersion equation for an elevated point source for average U.S. atmospheric stability conditions [26].

The maximum severity of pollutants may be calculated using the mass emission rate, Q, the height of the emissions, H, and the TLVs (used for noncriteria pollutants). The equations summarized in Table 18 are developed in Appendix C.

TABLE 18. POLLUTANT SEVERITY EQUATIONS FOR ELEVATED SOURCES

Pollutant	Severity equation
Particulate matter	$S_p = \frac{70\,Q}{H^2}$
Hydrocarbons	$S_{HC} = \frac{162\,Q}{H^2}$
Others	$S_a = \frac{5.5\,Q}{TLV \cdot H^2}$

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[26] Turner, D. B. Workbook of Atmospheric Dispersion Estimates. Public Health Service Publication 999-AP-26 (PB 191 482), U.S. Department of Health, Education and Welfare, Cincinnati, Ohio, 1969. 62 pp.

The ambient air quality standards used for criteria pollutants and the TLVs used for noncriteria pollutants are listed in Tables 19 and 20, respectively.

TABLE 19. AMBIENT AIR QUALITY STANDARDS FOR CRITERIA POLLUTANTS [24]

Emission	Ambient air quality standard, $\mu g/m^3$
Particulate matter	260
Hydrocarbons	160[a]

[a] The primary ambient air quality standard for hydrocarbons. The value of 160 $\mu g/m^3$ used for hydrocarbons in this report is a recommended guideline for meeting the primary ambient air quality standard for oxidants.

TABLE 20. THRESHOLD LIMIT VALUES (TLVs) USED FOR NONCRITERIA POLLUTANTS [25]

Emission species	TLV, mg/m^3	Comments
Biphenyl	1	
Dichlorobenzenes	300	*o*-dichlorobenzene - 300; *p*-dichlorobenzene - 450
Dimethyl phthalate	5	
Diethyl phthalate	5	
Dibutyl phthalate	5	
Di-C_8-alkyl phthalate	5	Di-sec octyl phthalate
Ethyl styrene	420	Styrene
Naphthalenes	50	Nathphalene
Phenols	19	Phenol
Alkylbenzenes	435	Ethyl benzene
Aluminum	10	Aluminum oxide
Calcium	2	Calcium oxide
Copper	1	
Iron	5	
Silver	0.1	
Sodium	2	Sodium hydroxide
Tin	2	

Using the above equations and previous emission factors, the source severity was calculated and the results are presented in Table 21. Except for particulate matter and total nonmethane hydrocarbons, the source severities for all organic and inorganic species were less than 0.001 and thus are not listed separately in the table.

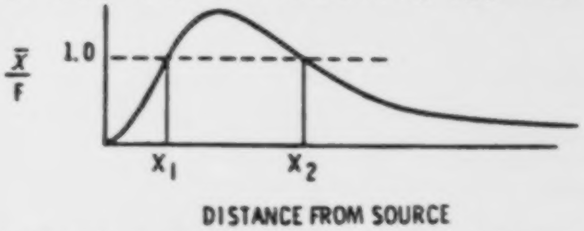
TABLE 21. SOURCE SEVERITY VALUES FOR AIR EMISSIONS FROM SELECTED UNIT OPERATIONS AT AN AVERAGE (11,400 kkg/yr) WOVEN FABRIC FINISHING PLANT[a]

	Source severity			
Emission species	Heat setting	Thermosol dye range	Resin finishing tenter frames	Resin finishing curing ovens
Particulate matter	0.03	0.03	0.06	0.02
Nonmethane hydrocarbon	0.17	0.12	0.82	0.68

[a] For an average stack height of 15 m.

Affected Population

Dispersion equations predict that the average ground level concentration, $\bar{\chi}$, varies with the distance, x, downwind from a source. For elevated sources, $\bar{\chi}$ is zero at the source (where $x = 0$), increases to some maximum value, $\bar{\chi}_{max}$, as x increases, and then falls back to zero as x approaches infinity. Therefore, a plot of $\bar{\chi}/F$ vs x will have the following appearance.



The affected population is defined as the number of nonplant persons around an average woven fabric finishing plant who are exposed to $\bar{\chi}/F$ ratio greater than 0.05 or 1.0. A severity of ≥1.0 indicates exposure to a potentially hazardous concentration of a pollutant. The severity value of 0.05 allows for inherent uncertainties in measurement techniques, dispersion modeling, and health effects data. The mathematical derivation of the affected population calculation is presented in Appendix C. The number of persons within the exposed area was calculated using a population density of 470 persons/km^2. This value was calculated by weighting the county population densities of the sources listed in the Predicast data by the number of sources in that county (see Appendix D). Values for the affected population around the average plant are listed in Table 22 for pollutants with severities greater than 0.05 and 1.0.

TABLE 22. AFFECTED POPULTATION VALUES FOR AIR EMISSIONS FOR $S_a \geq 0.05$

Emission species	Affected population from source, persons Heat setting	Thermosol dye range	Resin finishing tenter frame	Resin finishing curing ovens
Particulate	0	0	2	0
Total nonmethane hydrocarbon	102	87	510	476

CONTROL TECHNOLOGY

The textile manufacturing industry has not, by the nature of its operations, been one of the major sources of pollution in the United States and its air pollution problems have been considerably less severe than its wastewater problems. Therefore, due to its lower priority, this area is only beginning to receive attention within the industry and from the State and Federal enforcement agencies. Most of the air pollution abatement equipment in operation in textile mills today has only been recently installed, and its long term technical and economic performance has yet to be evaluated.

Several recent publications have compiled all relevant data and investigated air pollution control options [5, 7-9]. Therefore, this section will summarize the relevant findings.

As discussed earlier, air emissions from woven fabric finishing plants, excluding steam generation, include oil and acid mists, solvent vapors, odors, and dust and lint. Oil mists are produced when textile materials containing oils, plasticizers, and other materials that can volatilize or be thermally degraded into volatile organic species are subjected to higher temperatures (>100°C). Volatile material is driven off and is cooled into a blue haze of droplets, most of which are in the particle size range of 0.1 µm to 1.0 µm in diameter [5]. The most common source of oil mists is the tenter frame. Because of the higher operating temperatures (150°C to 200°C) organic species in the tenter frame exhausts are partially oxidized and, therefore, more odorous and corrosive than exhaust from lower temperature operations. Exhaust composition, as emphasized earlier, is a function of the fabric pre-history, and can contain oils, subliming dyes, carrier residues such as o-phenylphenol and its esters, brighteners, emulsifiers, glycerides, waxes, fatty acids and fatty acid phosphatides, plasticizers, resins, ethylene oxide, and lower molecular weight fractions of the synthetic fibers.

Acid mists are produced during the carbonizing of wool and during some types of spray dyeing and acetic acid mist dyeing. Because of their corrosive nature, some techniques for air pollution control to this type of dyeing are not applicable. Organic solvent vapors are released during and after solvent processing steps such as solvent dyeing and printing, and the application of finishes.

Odors are often associated with oil mists or solvent vapors and are removed by removal of the mist or by vapor recovery systems. The most common odor problems are the carrier odors from aqueous polyester dyeing and subsequent processes. Resin finishing also produces odors, chiefly formaldehyde. Other sources of odor include sulfur dyeing, reducing or stripping dyes with hydrosulfite, bonding, laminating, and bleaching with chlorine dioxide.

Air pollution control technology used within the woven fabric finishing industry to reduce hydrocarbon and particulate emissions is presented in the following subsection.

Scrubbers

Because of the emission of volatile organic compounds, some of which are quite odorous, several mills have installed wet scrubbers of various designs. The literature reports varying degrees of success for these units when they are applied to tentering operations [4, 7, 8, 27, 28]. Because oils in the gas stream are extremely difficult to dissolve in water, scrubbers may allow organic species to pass through the unit without capture.

A number of variations in scrubber design and application have been introduced by manufacturers. One of these variations uses petroleum oils instead of water as the absorbing medium [7, 8]. In this system, tenter frame off-gases are passed through a countercurrent packed column containing petroleum oils at 9°C. Other aqueous scrubbers use surfactants and alkaline additives to enhance collection of oils and organic species [4].

High-energy scrubbers have been applied to a lesser extent within the industry due to higher equipment and energy costs. However, there are plants which have installed venturi-type scrubbers

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[27] Beltran, M. R. How to Keep Tenter Frame Exhaust Air Clean. America's Textiles Reporter/Bulletin, November 1974. pp. 80-82.

[28] Northup, H. J., and W. F. Turner. Air Pollution Control in Textile Finishing. Textile Chemists and Colorist, 7(4):60-64, 1975.

ortenter frame exhausts utilizing surfactant and alkaline additives and operate at 30 to 35 inches of water pressure drop [4].

Carbon Adsorption

Activated carbon adsorption of volatile organic species and odors is sparsely applied in the textile manufacturing industry. However, there is increasing interest in this type of control technology because of the increased regulatory activity in controlling hydrocarbons, potential solvent recovery capabilities, and energy conservation [5, 29, 30].

In general, substances adsorb more readily (and are consequently more difficult to desorb) the higher their boiling boints. Adsorption also takes place more readily in small diameter pores than on open surfaces. Activated carbon adsorbs all organic species in preference to water while other adsorbents such as silica gel, synthetic zeolites, and metal oxides are more selective in the substance they will adsorb and, generally, will adsorb water in preference to organics [5]. Activated carbon is best employed for removal of organic substances with a molecular weight above 45 or a boiling point above 0°C. However, it is not advisable to use it for removal of high boiling oils, as these deactivate the charcoal by almost irreversible adsorption.

Carbon adsorption systems normally employ fixed beds of activated carbon. As the pollutant is adsorbed from the gas stream onto the bed, an adsorption zone is formed which moves through the bed at a velocity much slower than the gas velocity. The breakpoint (or breakthrough) is that time when the adsorption zone (or mass transfer zone) reaches the end of the bed, and the pollutant concentration of the bed effluent begins to increase. The effluent concentration increases with on-stream time, and at complete bed saturation will equal the influent concentration. Static equilibrium measurements of adsorption isotherms indicate the amount of organic adsorbed at saturation, but these data are not good design parameters since the onstream time of a fixed bed system is normally terminated short of complete saturation, usually soon after the breakpoint occurs [30].

When chlorinated solvents such as perchloroethylene, trichloroethylene, methylene chloride, and especially 1,1,1-trichloroethane

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[29] Chandrasekhar, R., and C. M. Yon. Fluidized Bed Activated Carbon Adsorption. Presented to the Symposium on Textile Industry Technology, Williamsburg, Virginia, December 5-8, 1978. 18 pp.

[30] Sheppard, W. M. Fixed Bed Carbon Adsorption for Control of Organic Emissions. Presented to the Symposium on Textile Industry Technology, Williamsburg, Virginia, December 5-8, 1978. 23 pp.

are steam stripped, hydrochloric acid is present in the bed. Since the activated carbon has catalytic properties, corrosion problems can be severe, and 304 and 316 stainless steel is not acceptable for carbon beds to recover chlorinated solvents. Most carbon adsorption systems are therefore lined with baked phenolic. A carbon bed for methylene chloride recovery with a baked phenolic coating can last 20 years under these conditions, while a bed of 304 stainless steel would last only 3 months [5].

Typically, activated carbon beds are arranged in parallel for continuous operation. While one bed is being stripped of substances, the other beds are adsorbing impurities from the exhaust. In some noncontinuous operations a single bed can be used if it has sufficient capacity to adsorb all the gaseous pollutants emitted from the process, and if it can be regenerated in time to be used the next time the process is performed.

Use of activated carbon adsorption and/or solvent recovery from textile plant exhausts is complicated by the variety of fabrics and associated treatments involved. The fabric itself or the colors and patterns are changed very frequently. The principal variable in fabric preparation is the inclusion or exclusion of scouring and the need for chlorinated solvent scouring, as with some polyester fabrics, versus the use of water and detergents, as with most other fabrics.

In printing, combinations of certain dyes with acetate or acrylic fabrics causes emissions. Most other operations only evolve water vapor. If print pastes used with cotton or rayon fabrics include quantities of urea, emissions of urea can be expected.

The final finishing step basically involves the application of resins, most based on formaldehyde polymers, to bestow properties such as antistat, crease resistance and waterproofing, and heat setting the resin in a tenter frame at high temperatures. The resin formulations change with both the fabric as well as the kind of property imparted to the fabric.

Various paremeters significantly affect the performance of an activated carbon adsorber. These include temperature, species of hydrocarbons and their concentrations, quantity of moisture present, and dust loading. The sizing of the adsorber, choice of carbon type, the choice of configurations, mode of desorption, materials of construction, and selection of ancillary equipment for pre-or post-treatment of the exhaust gases are highly dependent on these parameters as well as the presence of toxic or odorous compounds.

Textile plant exhaust temperatures approach or exceed normal desorption temperature of activated carbon. These gases, therefore, require precooling prior to entering the adsorber. The degree of precooling usually prescribed can easily be carried out either with cooling tower water or with gas/gas heat exchangers depending on the reuse economics of the recovered heat. Close attention must be paid to undesirable condensation of vapors in the heat exchanger. Lower inlet concentrations may require lower inlet temperatures if hydrocarbon recovery required is a very high percentage of the inlet concentration.

Relative humidities of up to 50 percent at 38°C have been easily handled in carbon bed adsorbers. Depending on the mode of desorption, products end up with 2 to 20 percent water. Higher moisture content of the exhaust gases result in more water in the product. Special dehumidification may be required if the humidity far exceeds 50 percent.

Dust, in finishing plants, appears in the form of lint. Unless it is sticky or rendered sticky prior to entering the adsorber and likely to clog the distributor plates, dust will pass right through the system without affecting performance.

Incineration

Three methods of incineration are available: open flame incineration, direct flame incineration, and catalytic oxidation. Of the various methods, open flame burning is the least reliable, since the contact time between the flame and organic pollutant is usually too short to insure complete destruction. It can produce soot, carbon monoxide, and partially oxidized hydrocarbons that may be more objectionable than the original substance [5, 31, 32].

Direct flame incineration is more widely used throughout the textile manufacturing industry to reduce organic emissions than any other control device. This technology requires heating of the pollutant-air mixture to 750°C to 850°C for 0.3 s to 0.5 s, generally in an externally heated combustion chamber [5]. Since liquid, solid, and vaporized organic species are all oxidized, no pre-filter is required to remove lint. Heat recovery systems usually double the initial investment cost, but halve the operating cost.

Catalytic incineration is basically the same chemical process as direct flame incineration, except that the catalyst initiates the reaction at much lower temperatures (250°C to 450°C). Oxidation catalysts are generally of the platinum group of metals, or

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[31] Githens, R. E., and D. M. Sowards. Catalytic Oxidation of Hydrocarbon Fumes. Presented to the Symposium on Textile Industry Technology, Williamsburg, Virginia, December 5-8, 1978. 9 pp.

[32] Prowler, M. E. Roof-Top Incinerator Prevents Air Pollution. Environmental Control Safety Management, 141(2):18-19, 1971.

copper or silver. They are placed into a monolithic honeycomb structure made of various grades of alumina or other ceramics. Cylindrical pellets are another type of substrate or support [5, 31].

The most serious problem with catalytic emission destruction is loss and deactivation of the catalyst. Catalyst losses are due primarily to abrasion, which is especially severe with heavy particulate loading. Deactivation occurs because of clogging with particulates, carbonization on the catalyst surface or in the pores, and poisoning. Metallic and organometallic vapors of arsenic, lead, zinc, and mercury are the most common catalyst poisons, and they may be present in textile manufacturing exhausts due to fire retardant chemicals and organic dyes.

Applications of catalytic incinerators in the textile industry are on Thermosol oven and tenter frame exhausts [31].

Process Controls

The application of control devices to the effluent gas streams from tenters and curing ovens tends to attack the problem as it presently exists, including all of the uncertainties and variabilities related to process conditions. One approach to organic emission control that warrants more attention is the reduction of emissions at their source. This involves a critical review of the processes themselves with the following objectives:

- Reducing the level of organics in the fabrics entering the tenter frame or curing oven
- Substituting less volatile reagents to accomplish the same desired end product
- Reducing both the air flow and the operating temperatures of the equipment to accomplish the same desired end point.

One company has made significant progress in reducing its overall emission problems by such analysis of its operations [7, 8]. Operating temperatures in its curing/finishing tenters have been reduced through changes in the resin/catalyst system. Higher emission-producing operations have been identified and limited to one specific tenter frame equipped with an air/air heat exchanger and a high-energy demister control system. It should be noted that reduced operating temperatures in the finishing oven reduce not only the visible emission level, but also the noncondensible hydrocarbon levels.

Another company, after a similar analysis of its operations, completely eliminated its emissions problem in a large screen printing installation by shifting from oil-based to water-based media [7, 8].

Since oil mists are cuased by evaporation of oils from textile materials, their formation can be prevented by reduction of the oil content of the materials prior to heat treatment. Careful control of the application of spinning oils and fabric finishes to prevent excessive buildup on the fabric can reduce mist problems and simultaneously result in material savings. Scouring before tentering rather than after is possible in some cases, though in others tentering is required before scouring to impart dimensional stability to the fabric. To eliminate oil mist problems from tenter frames, input oil content must be reduced to below 0.5 weight percent [5].

Careful control of the heat input to the fabric can also prevent excessive oil evaporation as well as save energy. Dielectric dyeing and curing are feasible in some instances, either as total replacements for other forms of energy input or as supplementary energy inputs to effect precise energy control. Dielectric energy as an input source is inherently self-regulating since the rate at which any material absorbs dielectric energy is proportional to its dielectric constant. Water, with a high dielectric constant, absorbs energy rapidly and is dried from the fabric. When the fabric is dry, overheating does not occur, because the dielectric constant of the fibers is much lower. Dielectric heating can also be employed as a means of precise energy input in the curing of plastisols. While economics have previously not favored dielectric heating, the rising cost of energy and the increasing stringency of antipollution laws are making it increasingly attractive.

Odor problems can often be eliminated or reduced if the processes involved are modified so that the odor causing chemicals are eliminated or emitted in smaller amounts, or so that other vapors are emitted which are either less odorous or easier to remove from the atmosphere.

In the case of polyester dyeing, pressure dyeing will produce fewer odor problems than atmospheric dyeing, since the required carrier concentration is lower. Substitution of solvent dyeing for aqueous dyeing can eliminate carrier odors, since no carrier is necessary with solvent systems. With existing processes, where major changes in equipment would not be feasible, it is often possible to substitute less odorous carriers, or carriers that are easier to mask or to treat with inexpensive techniques. Optimization of carrier concentration and of the time-temperature cycle for dyeing can sometimes result in decreased carrier consumption.

In cases where the odorous compound is generated in the process or is present in excess concentration, it can sometimes be removed by addition of chemicals that will react with it. One example is the use of formaldehyde acceptors to react with the excess of free formaldehyde present in the resin finishing. This example also illustrates the limitations of such a solution because in some cases the formaldehyde acceptors will also react with formaldehyde in the resin itself, destroying fabric properties such as wash-wear and smoothness. If this reaction continues during storage of the fabric, amine odors are produced. Formaldehyde acceptors have been used successfully for many years, but they require extreme care in application [5].

Good housekeeping and proper maintenance of existing antipollution equipment can alleviate some odor problems. Proper adjustment of air flow rates to the odor abatement system can sometimes result in reduced volumes of air to be processed and, therefore, in greater efficiency of odor removal at lower operating cost.

In some cases, an odorous compound is applied to the fabric that comes off gradually in later processes. Immediate and thorough drying can result in this compound's removal at a single location, simplifying odor collection problems. There exist nonodorous deformers that perform as well as the odorous ones. Other oxidizing agents can sometimes be substituted for chlorine dioxide in the bleaching process.

SECTION 5

WASTEWATER EFFLUENTS AND CONTROL TECHNOLOGY

INTRODUCTION

The woven fabric finishing segment is the largest volume discharger in the textile manufacturing industry. Of those woven fabric finishing plants reporting data, 32% (87 plants) had discharge rates greater than 1,900 m^3/day (0.5 mgd), compared with 15% (156 plants) for the rest of the textile manufacturing industry [2]. Table 23 gives the breakdown of plants that discharge directly to receiving streams and those that discharge indirectly through Publically Owned Treatment Works (POTW).

TABLE 23. NUMBER OF DIRECT AND INDIRECT DISCHARGERS FOR TEXTILE WOVEN FABRIC FINISHING PLANTS [2]

Discharge type	Number of plants	Percent of total plants
Direct	82	24.4
Indirect	224	66.7
Unknown	30	8.9
Total	336	100

During the development of effluent standards for this industry, three subdivisions were identified as having distinctive wastewater characteristics [1]: (a) simple processing, (b) complex processing, and (c) complex processing plus desizing.

- Simple processing covers facilities that perform fiber preparation, desizing, scouring, functional finishing, and/or one of the following processes applied to more than five percent of total production: bleaching, dyeing, or printing. This subdivision includes all woven fabric finishing plants that do not qualify under either the complex processing or complex processing plus desizing subdivision.

- Complex processing includes facilities that perform fiber preparation, desizing of less than 50% of their total production, scouring, mercerizing, functional finishing, and more than one of the following, each applied to more than five percent of total production: bleaching, dyeing, and printing.

- Complex processing plus desizing differs from complex processing only in that it covers those facilities that desize more than 50% of their total production.

Complex processing plus desizing was identified as a separate subdivision because desizing is a major (>50%) contributor to the 5-day biochemical oxygen demand (BOD_5) loading [1].. Water usage data and total mill wastewater discharge data for each subdivision are given in Table 24. Complex processing plus desizing, as noted in the table, require the most water per unit of production.

WASTEWATER SOURCES AND CHARACTERIZATION

Wastewaters from woven fabric finishing plants arise from both point and nonpoint sources. Point sources are those which originate as a definite wastewater stream from a particular process. Nonpoint sources originate from random leaks and spills at the plant, equipment washdown, and from rainfall runoff. The eight types of point sources found in this industry category include:

- desizing
- scouring
- bleaching
- mercerizing
- dyeing
- printing
- functional finishing
- sanitary wastes

Figure 8 gives a flow diagram of a typical plant, showing the different unit processes and the corresponding wastewater streams. As discussed earlier the actual number of process operations at a site varies from plant to plant, although effluents from each process are generally combined before discharge from the plant. This arrangement is important in understanding wastewater characterization data, because most data come from analysis of the total plant effluent. A qualitative description of the wastestreams from the individual point and nonpoint sources is given in the following paragraphs. The important pollutant parameters for these wastestreams include: 5-day Biochemical Oxygen Demand (BOD_5); Chemical Oxygen Demand (COD); solid materials, expressed as Total Dissolved Solids (TDS) and Total Suspended Solids (TSS); oil and grease; pH; chromium; and color.

TABLE 24. WATER USAGE DATA AND TOTAL PLANT WASTEWATER DISCHARGE DATA FOR TEXTILE WOVEN FABRIC FINISHING PLANTS [2]

Category	Number of plants surveyed	Water usage, m^3/kg of production (gal/lb)			Wastewater discharge rate, m^3/day (MGD)			
		Minimum	Maximum	Median	Minimum	Maximum	Average	Median
Simple processing	48	0.012 (1.5)	0.28 (33.1)	0.078 (9.4)	57 (0.015)	20,800 (5.495)	1,970 (0.520)	636 (0.168)
Complex processing	39	0.011 (1.3)	0.28 (33.2)	0.087 (10.4)	47 (0.012)	28,900 (7.635)	4,280 (1.131)	1,530 (0.405)
Complex processing plus desizing	50	0.005 (0.6)	0.51 (60.9)	0.11 (13.6)	34 (0.009)	20,900 (5.495)	1,890 (0.499)	636 (0.168)
Total of all plants	137	0.005 (0.6)	0.51 (60.9)	0.094[a] (11.2)[a]	34 (0.009)	28,900 (7.635)	2,599 (0.686)	891[a] (0.235)[a]

[a] Average of the medians.

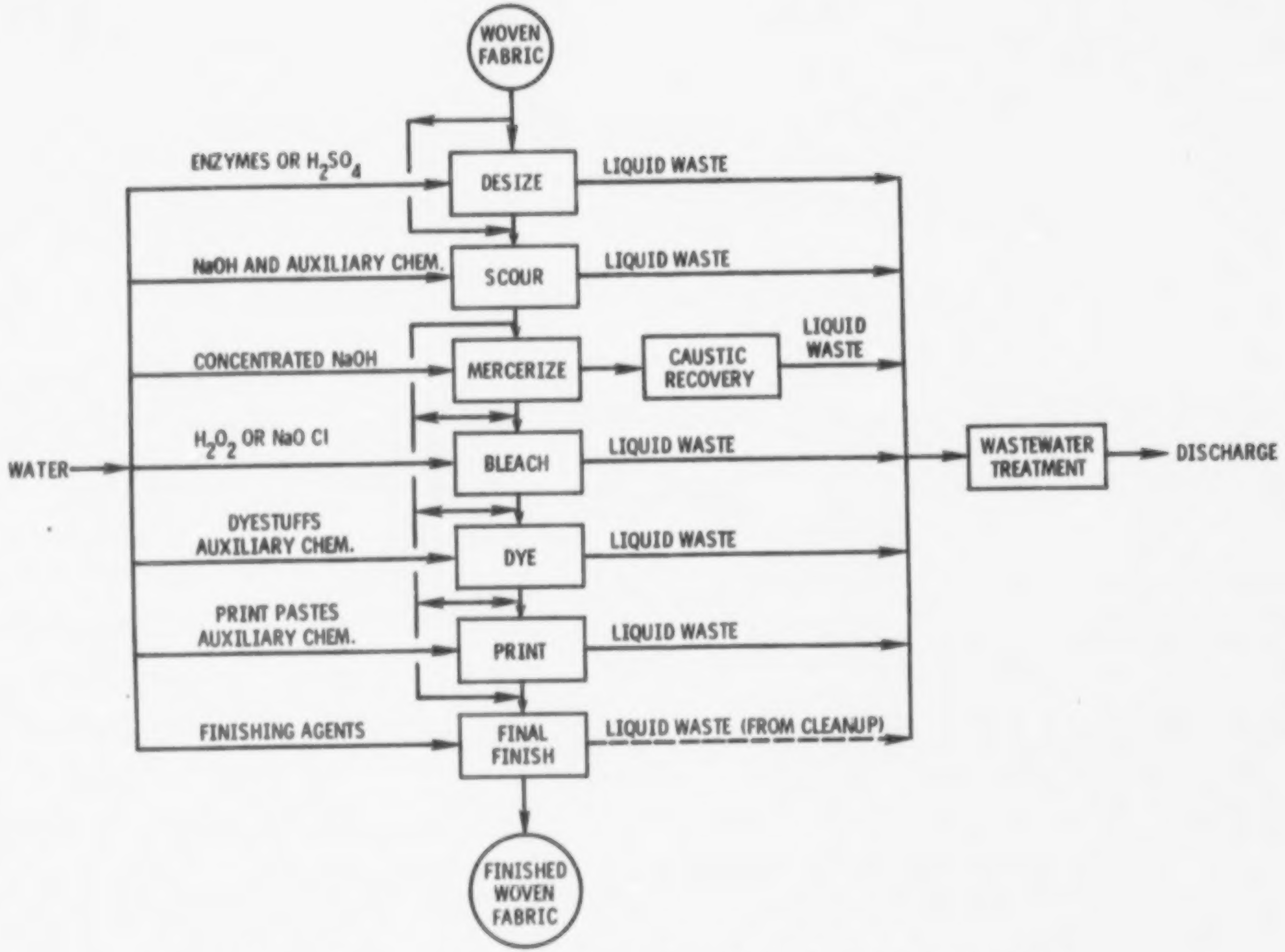
WOVEN FABRIC
ENZYMES OR H_2SO_4
DESIZE
LIQUID WASTE
NaOH AND AUXILIARY CHEM.
SCOUR
LIQUID WASTE
CONCENTRATED NaOH
MERCERIZE
CAUSTIC RECOVERY
LIQUID WASTE
WATER
H_2O_2 OR NaO Cl
BLEACH
LIQUID WASTE
WASTEWATER TREATMENT
DISCHARGE
DYESTUFFS AUXILIARY CHEM.
DYE
LIQUID WASTE
PRINT PASTES AUXILIARY CHEM.
PRINT
LIQUID WASTE
FINISHING AGENTS
FINAL FINISH
LIQUID WASTE (FROM CLEANUP)
FINISHED WOVEN FABRIC

Figure 8. Flow diagram of wastewater sources at a typical woven fabric finishing plant [2].

Desizing

Desizing contributes a significant amount (>50%) of organic load, some oil and grease, and most of the suspended material found in woven fabric finishing wastewater. Desizing may contribute 50% or more of the total waste solids found in the wastewater. There are two types of sizes used that determine the character of the wastewater:

- Synthetic sizing agents: polyvinyl alcohol (PVA), carboxymethyl cellulose (CMC), and polyacrylic acid (PAA)
- Natural starch size

Synthetic sizing agents, tending to be less biodegradable unless exposed to an acclimated biological environment, result in an increase of COD. They are soluble in water and can be removed from woven fabric without difficulty.

Natural starch size is high in BOD and is not readily soluble. In order to facilitate removal, it can be hydrolized into a soluble form by the action of special enzymes or by acid solutions. Table 25 lists the materials generated by each removal process and the characteristics of the waste. The wastewater pH from enzyme removal is about neutral (pH 7) while that from sulfuric acid removal is acidic (pH 1 to 2).

TABLE 25. WASTEWATER COMPOSITION DURING REMOVAL DESIZING OF NATURAL STARCH SIZE [2]

Type of removal	Wastes generated	Waste characteristics
Enzymatic removal	Starch solids, fat, wax, enzymes, sodium chloride, wetting agents	Organic and inorganic dissolved solids, suspended solids, some oil and grease, pH 6 to 8, color: light
Sulfuric acid removal	Starch solids, fat, wax, sulfuric acid	Organic and inorganic dissolved solids, suspended solids, some oil and grease, pH 1 to 2, color: relatively light

For the average woven fabric finishing mill processing 100% cotton goods with starch used as the sizing agent, the desizing waste will generally constitute about 16% of the total wastewater volume, 5% of the BOD, 36% of the total solids, and 6% of the alkalinity [2].

Scouring

Scouring is done to remove much of the natural impurities of cotton. A 2% to 3% solution of sodium hydroxide is typically used, with possible auxiliary chemicals such as phosphate, chelating agents, and wetting agents. Scouring liquors are strongly alkaline (pH greater than 12), and dark colored due to cotton impurities. The liquors contain dissolved solids, oil and grease, and some suspended solids from the presence of cotton impurities.

Synthetic fibers are relatively free of natural impurities so they require much less vigorous scouring. Scouring of synthetic fibers generates low levels of dissolved solids from surfactant, soda ash, or sodium phosphate [2, 3].

For the typical woven fabric finishing plant processing 100% cotton goods, the scouring waste will generally constitute 19% of the total wastewater volume, 37% of the BOD, 43% of the total solids, and 60% of the alkalinity [2].

Bleaching

Most (>50%) cotton bleaching is done with hydrogen peroxide or hypochlorite. Hydrogen peroxide bleaching contributes very small waste loads, most of which are dissolved solids, in comparison to sizing and scouring wastewaters. The dissolved solids contain both inorganic (sodium silicate, sodium hydroxide, and sodium phosphate) and organic (a surfactant and a chelating agent) species. The waste stream contains a low level of suspended solids (fibers and natural impurities) when goods containing cotton are bleached [2, 3].

Mercerization

Mercerization wastes predominantly consist of sodium hydroxide used in the process. The waste stream contains higher levels of dissolved solids than scouring and has a pH of 12 to 13. Depending on whether mercerization is practiced before or after bleaching, smaller amounts of foreign material and wax may be removed from the fiber and will appear as suspended solids, oil and grease.

For the typical woven fabric finishing plant processing 100% cotton goods, mercerizing waste will contribute about 1% of the BOD load [2].

Today, mercerization is practiced less often and those plants that do use it have found it economically attractive to recovery of the sodium hydroxide used for reuse. Consequently, the waste contribution due to mercerization has become even less significant at many plants [2].

Dyeing

Dyeing is the most complex of all the wet finishing operations. Depending on the types of fabric, the types of dyes used, the types of equipment employed, and the efficiency of the processes, the waste stream from the dyeing of woven fabric may contain any combination of the dyes and auxiliary chemicals.

Dyeing can contribute substantially to the total waste load and is responsible for most of the waste volume. Color is an obvious waste. High levels of dissolved solids are present and the suspended solids are relatively low.

For various woven fabric finishing mills that process 100% cotton, dyeing was found to contribute 1.5% to 30% of the total BOD [2].

Printing

Although the wastewater volumes are much lower and the concentration greater, printing wastes are comparable in many respects to dye wastes. The chemicals used in printing will contribute BOD and printing pigments will contribute some suspended solids when the fabric is rinsed. Solvents (varsol) and glycerine are also common constituents found in printing wastes. Much of the waste from printing comes from the cleaning of make-up tanks and process equipment. The relatively concentrated waste from printing may justify segregated treatment [2, 3].

Functional Finishing

Wastes from resin treatment, waterproofing, flameproofing, and soil release are small, since the chemicals are applied by padding followed by drying and curing. The range of chemicals used in special finishes is very broad, and small amounts of them will enter the wastes [3].

Sanitary Wastes

Various treatment approaches are used in dealing with sanitary wastes. In one industry study of 11 plants, the method most commonly employed was found to be no treatment at all prior to combination with industrial wastes. One plant provided chlorination for its sanitary waste prior to further treatment with industrial wastes. Another had a separate treatment facility (oxidation pond) for their sanitary wastes. For these 11 plants sanitary wastes were found to contribute up to 7.5% of the total wastewater volume [33].

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[33] Engineering Science, Inc. Textile Mill Draft Report: Plant B, C, H, J. K, M, U, V, and Z. U.S. Environmental Protection Agency, 1978-1979.

Nonpoint Sources

Wastewater nonpoint sources found in woven fabric finishing plants can be caused by leaking pumps, compressors, heat exchangers, or other similar equipment, and by random spills [5]. Good housekeeping procedures can keep wastewaters from nonpoint sources to a minimum.

EFFLUENT DATA

Historical wastewater data for conventional and nonconventional pollutants were collected from manufactureres and then compiled in a study by Svedrup and Parcel [2]. The historical data were supplemented by field sampling data from a recent joint study conducted by the American Textile Manufacturers Institute (ATMI) and the U.S. Environmental Protection Agency (EPA). In this joint study the EPA and ATMI selected a total of 23 textile plants representing eight textile processing categories and having well-operated secondary wastewater treatment facilities to determine the best available technology economically available (BATEA) for textile plant wastewaters. Eleven of these 23 selected textile plants were in the subcategory of woven fabric finishing. The field sampling tests also obtained data for priority pollutants and other metals since historical data are not available for these two pollutant classes [34, 35].

A summary of historical data for conventional and nonconventional pollutant parameters as obtained by Svedrup and Parcel, is presented in Table 26 for raw wastewaters from woven fabric finishing plants. The secondary effluent historical data summary from plants practicing the best practicable technology (screening, equalization, neutralization, aeration basin, secondary clarification) are given in Table 27. Although it is possible to subdivide the woven fabric finishing plants into simple processing, complex processing, and complex processing plus desizing, based on the BOD and COD values of the raw wastewater (Table 26), this subdivision is not possible based on the BOD and COD values of the BPT effluents (Table 27). The maximum and average concentrations found in Table 27 will be used later in evaluating the potential environmental impact of wastewaters from woven fabric finishing plants. Since it is not possible to subdivide woven

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[34] Rawlings, G. D. Source Assessment: Textile Plant Wastewater Toxics Study, Phase I. EPA-600/2-78-004h. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. March 1978.

[35] Klieve, J. R., and G. D. Rawlings. Source Assessment: Textile Wastewater Toxics Study, Phase II. EPA-600/2-79-019i, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. December 1979. 141 pp.

TABLE 26. RAW WASTEWATER CHARACTERISTICS - SUMMARY OF DATA REPORTED BY WOVEN FABRIC FINISHING PLANTS (HISTORICAL DATA) [2]

		Quality of pollutant, kg/kkg of product				
Pollutant parameter	Subcategory	Minimum	Maximum	Average	Median	No. of plants
5-Day biochemical oxygen demand (BOD_5)	Simple processing	3.77	215.35	36.75	22.64	32
	Complex processing	3.59	96.05	36.99	32.74	23
	Complex processing plus desizing	5.90	188.51	53.57	45.12	36
	The three subdivisions combined	3.77	188.51	43.51	34.12	91
Chemical oxygen demand (COD)	Simple processing	12.70	436.82	108.00	92.40	28
	Complex processing	10.18	388.01	128.28	110.62	12
	Complex processing plus desizing	48.04	798.32	157.27	122.63	29
	The three subdivisions combined	12.70	388.01	132.22	108.27	69
Total suspended solids (TSS)	Simple processing	0.81	222.11	27.23	7.96	26
	Complex processing	1.95	61.68	14.95	9.63	18
	Complex processing plus desizing	0.20	83.50	23.17	14.76	28
	The three subdivisions combined	0.20	222.11	22.58	11.02	72
Oil and grease	Simple processing	0.65	151.25	25.31	9.08	11
	Complex processing	2.24	14.24	5.52	3.84	6
	Complex processing plus desizing	0.36	14.93	5.22	4.08	5
	The three subdivisions combined	0.36	150	15	6.5	22
Phenol	Simple processing	1.76	51.21	14.29	8.15	10
	Complex processing	0.91	25.03	10.33	7.69	4
	Complex processing plus desizing	0.93	149.32	52.69	13.10	6
	The three subdivisions combined	0.91	149.32	25.02	9.54	20
Total chromium	Simple processing	0.07	43.76	8.19	4.30	16
	Complex processing	2.37	49.23	15.32	2.62	7
	Complex processing plus desizing	0.57	1,521.01	239.58	20.86	11
	The three subdivisions combined	0.07	1,521.01	84.64	9.32	34
Sulfide	Simple processing	0.58	128.21	28.24	7.59	6
	Complex processing	7.84	19.88	13.41	12.51	3
	Complex processing plus desizing	15.73	293.72	154.72	154.72	2
	The three subdivisions combined	0.58	293.72	47.21	35.7	11
Color, APHA units	Simple processing	20	10,000	2,500	800	9
	Complex processing	320	700	508	508	2
	Complex processing plus desizing					0
	The three subdivisions combined	20	10,000	2,100	750	11

Note. Blanks indicate data not available.

TABLE 27. BPT EFFLUENT CHARACTERISTICS - SUMMARY OF DATA REPORTED BY WOVEN FABRIC FINISHING PLANTS (HISTORICAL DATA) [2]

		Quality of pollutant, kg/kkg of product				
Pollutant parameter	Subcategory	Minimum	Maximum	Average	Median	No. of plants
5-Day biochemical oxygen demand (BOD_5)	Simple processing	0.79	18.77	4.78	2.59	7
	Complex processing	0.54	15.04	4.94	4.05	7
	Complex processing plus desizing	0.51	13.65	3.12	2.14	17
	The three subdivisions combined	0.51	13.65	3.91	2.67	31
Chemical oxygen demand (COD)	Simple processing	17.67	71.71	38.43	33.62	6
	Complex processing	17.87	109.98	47.59	39.03	6
	Complex processing plus desizing	4.69	82.03	34.49	29.40	13
	The three subdivisions combined	17.87	82.03	38.58	32.72	25
Total suspended solids (TSS)	Simple processing	2.27	11.26	6.31	4.76	7
	Complex processing	3.20	10.11	6.65	7.55	7
	Complex processing plus desizing	0.65	19.38	6.00	4.56	17
	The three subdivisions combined	0.65	19.38	6.22	5.28	31
Oil and grease	Simple processing			5.18 (24)		1
	Complex processing					0
	Complex processing plus desizing	0.42	3.30	1.29	1.05	5
	The three subdivisions combined	0.42	3.30	1.94	1.05	6
Phenol	Simple processing	1.57	14.15	5.63	2.78	7
	Complex processing	3.42	73.80	31.52	17.35	3
	Complex processing plus desizing	0.24	72.79	13.63	3.01	8
	The three subdivisions combined	0.24	72.79	13.50	5.31	18
Total chromium	Simple processing	1.21	37.17	8.28	2.61	7
	Complex processing	1.42	32.89	11.66	3.70	5
	Complex processing plus desizing	0.08	106.56	12.04	2.45	12
	The three subdivisions combined	0.08	106.56	10.86	2.76	24
Sulfide	Simple processing	8.93	24.24	16.58	16.58	2
	Complex processing	3.74	27.57	12.09	9.60	5
	Complex processing plus desizing	33.57	155.93	93.53	92.3	4
	The three subdivisions combined	3.74	155.93	42.52	40.94	11
Color, APHA units	Simple processing			337		1
	Complex processing					0
	Complex processing plus desizing			118		1
	The three subdivisions combined			228		2

Note. Blanks indicate data not available.

fabric finishing into simple processing, complex processing, and complex processing plus desizing based on BPB effluent data, the maximum concentration values used will be the maximum of the three subdivisions maximums, and the average used will be the averages of the three averages reported.

Plant Specific Data

Specific manufacturers report data (historical data) supplemented by field sampling data on conventional and nonconventional pollutants for the 10 woven fabric finishing plants studied in the EPA/ATMI study [34]. These data are presented in Table 28. Ranges for the 30-day average and maximum were given to illustrate that these plants were not necessarily at these highest concentration value for a one-year period.

Where field sampling data were used, the maximum flow rate for a one-year period, and the top of the range of the mean flow rate for a one-year period was used. Table 28 also provides the average plant production and the percentage of that production covered under a different textile plant subcategory other than woven fabric finishing, the range of the average (along with the average) and maximum flow rate for a one-year period, and the percent sanitary wastes.

Priority Pollutants

The EPA developed a list of 129 priority pollutants which they will consider in their standards setting process. A list of these 129 priority pollutants is given in Appendix E. From field sampling conducted by the EPA and ATMI, priority pollutant data for 11 woven fabric finishing plants were available [34]. Table 29 gives the concentrations of the priority pollutants found in the raw wastewater (influent) and secondary effluent for the 10 plants. To illustrate the number of appearances organic pollutants made in the 11 woven fabric finishing plants, influent and secondary effluent, Figures 9 and 10 were constructed.

Other Metals

In addition to the conventional and nonconventional pollutants, and the 129 priority pollutants, 15 metals were measured in the influent and secondary effluents of the 10 woven fabric finishing plants. These values are given in Table 29. The 15 metals are: aluminum, barium, boron, calcium, cobalt, iron, magnesium, manganese, molybdenum, sodium, silicon, tin, phosphorus, titanium, and vanadium.

POTENTIAL ENVIRONMENTAL IMPACT

In this subsection, factors that bear on the evaluation of the potential environmental effects of a particular wastewater

TABLE 28. CONVENTIONAL AND NONCONVENTIONAL POLLUTANT DATA, AND PLANT SPECIFIC DATA FOR 10 WOVEN FABRIC FINISHING PLANTS [3, 5, 6]

Parameter	Plant B		Plant C		Plant E	
	30-day average	Maximum	30-day average	Maximum	30-day average	Maximum
BOD_5, mg/L	12 to 27	19 to 43	10.7 to 40	19 to 132	<5	
COD, mg/L	178 to 235	216 to 281	318 to 628	446 to 1,576	78	
TSS, mg/L	11 to 44	30 to 98	23.3 to 240	8	19	
Phenol, mg	0.015[b]		0.0018 to 0.028	0.01 to 0.028	0.014	
Total chromium, mg/L			<0.005 to <0.099	<0.005 to <0.11		
Sulfide, mg/L	0.2		<0.210 to 16.9	0.38 to 28.8	<1	
Color, APHA	90		1,920		30	
pH	7.1 to 7.7	7.5 to 8.8	8.00 to 9.38	8.8 to 10.3	7.1	7.6
Production rate, kg/day	43,100		95,100		170,000	
Discharge flow rate, MGD	0.57 to 0.96	1.1 to 1.5	1.63 to 3.73	3.5 to 4.8	2.17	
Percent sanitary waste	2	<0.5%			3	

Parameter	Plant H		Plant J		Plant K	
	30-day average	Maximum	30-day average	Maximum	30-day average	Maximum
BOD_5, mg/L	13 to 43	28 to 79	16 to 57	21 to 73	5.3 to 12.3	10 to 17
COD, mg/L	274 to 549	385 to 967	291 to 594	394 to 763	75 to 426	132 to 639
TSS, mg/L	28 to 108	37 to 239	13 to 63	25 to 229	4.6 to 14.3	8 to 20
Phenol, mg/L	0 011 to 0.032	0.015 to 0.045	0.024		0.018	
Total chromium, mg/L	0.004 to 0.013	0.011 to 0.023			<0.04	<0.04
Sulfide, mg/L	0.02 to 0.09	0.1 to 0.2	1.8		<1	
Color, APHA	500		1,375		131	
pH	7.2 to 7.8	8.4 to 9.4	8.0 to 8.8	8.9 to 9.4	8.3 to 9.0	8.5 to 9.0
Production rate, kg/day	85,500		177,000		76,200	
Discharge flow rate, MGD	2.33 to 2.62	2.5 to 3.7	2.74 to 4.64	4.5 to 8.5	1.6 to 2.35	2.8 to 3.4
Percent sanitary waste	<1		4		7.5	

(continued)

TABLE 28 (continued)

Parameter	Plant M 30-day average	Plant M Maximum	Plant U 30-day average	Plant U Maximum	Plant V 30-day average	Plant V Maximum
BOD_5, mg/L	8.9 to 12	12 to 17	9 to 55	15 to 265	1.4 to 12	2 to 17
COD, mg/L	499 to 546	696 to 1,120	314 to 1,500	455 to 5,886	75 to 216	75 to 216
TSS, mg/L	15 to 143	32 to 396	177	749	11 to 47	18 to 59
Phenol, mg	0.02 to 0.03	0.04	0.02	0.09	0.01 to 0.09	0.01 to 0.09
Total chromium, mg/L			<0.02 to 0.011	<0.02 to 0.047	0.007 to 0.017	0.008 to 0.024
Sulfide, mg/L	0.07 to 0.15	0.64 to 0.8	3.5		<1	
Color, APHA	500		2,480		500	
pH	7.0 to 8.5	7.7 to 13	5.8 to 6.9	7.5 to 8.6	6.7 to 6.9	7.0 to 7.6
Production rate, kg/day	334,000		32,000		15,600	
Discharge flow rate, MGD	7.34 to 8.78	9.o to 11.8	0.24 to 0.52	0.5 to 1.0	0.15 to 0.74	0.4 to 1.3
Percent sanitary waste	1		0		5	

Parameter	Plant Z 30-day average	Plant Z Maximum
BOD_5, mg/L	2.3 to 24	2.5 to 42
COD, mg/L	99 to 207	109 to 308
TSS, mg/L	2.9 to 58	36 to 207
Phenol, mg	0.01 to 0.09	0.01 to 0.19
Total chromium, mg/L	0.01 to 0.023	0.01 to 0.03
Sulfide, mg/L	<0.1 to <10	<10
Color, APHA	750	
pH	7.8 to 8.1	8.4 to 10
Production rate, kg/day	33,000	
Discharge flow rate, MGD	1.75 to 2.34	2.5 to 3.0
Percent sanitary waste	5	0.5

[a] Flow rate (mean-maximum) is MGD for month producing highest concentration value.

[b] Data from Reference 6.

[c] Reference 5.

[d] Subcategory 3 of 3 of Textile Plants: Dry Processing.

[e] Subcategory 5 of Textile Plants: Knit Fabric Finishing.

[f] Subcategory 7 of Textile Plants: Stock and Yarn, Dyeing and Finishing.

Note: Blanks indicate data not available.

TABLE 29. PRIORITY POLLUTANT CONCENTRATIONS FOR INFLUENT AND EFFLUENT STREAMS AT 10 WOVEN FABRIC FINISHING PLANTS [34, 36]

	Concentration, μ/gL											
	Plant B		Plant C		Plant E		Plant H		Plant J		Plant K	
Priority pollutant	Influent	Secondary Effluent	Influent	Secondary Effluent	Influent	Secondary Effluent	Influent	Secondary Effluent	Influent	Secondary Effluent	Influent	Secondary Effluent
Acenaphthene	-[a]			0.5			27					
Benzene					5.4							
Chlorobenzene					1.0							
1,2,4-trichlorobenzene				10.2								
Hexachlorobenzene												
1,1,1-trichloroethane					16.7							
1,1-dichloroethane												
2,4,6-trichlorophenol											0.7	
p-chloro-m-cresol							4.5					
Chloroform	3.04				21.5						4.8	58.1
2-chlorophenol												
1,2-dichlorobenzene			1.1	0.3		0.2	0.5					
1,4-dichlorobenzene					2	0.2						
1,2-Trans-dichloroethylene					1.8							
1,2-dichloropropane												
1,2-dichloropropylene												
Ethylbenzene			112	2.0	20.7		5.7			50.8	63.8	0.7
Methylene chloride[b]				(160)[a]								
Dichlorobromomethane		2.60		(0.6)				2,138				
Trichlorofluoromethane												
Naphthalene	41				1		3		79.7		0.03	0.5
2-nitrophenol							60					
4-nitrophenol							65					
N-nitrosodiphenylamine												
N-nitrosodi-n-propylamine		2										
Pentachlorophenol					30.1						3.9	
Phenol			0.5	(0.4)	5.7		63					
Bis(2-ethylhexyl) phthalate	5.7	3	136	3.0	5	18	14	231	162	35.2		8
Di-n-butyl phthalate				(0.6)			2		23.2	3.6		
Diethyl phthalate	3.3		4.1			0.5			6.5		0.2	
Dimethyl phthalate						1						
Anthracene	0.1											

	Concentration, μ/gL							
	Plant M		Plant U		Plant V		Plant Z	
Priority pollutant	Influent	Secondary Effluent	Influent	Secondary Effluent	Influent	Secondary Effluent	Influent	Secondary Effluent
Acenaphthene					8.7			
Benzene								
Chlorobenzene								3.5
1,2,4-trichlorobenzene	156	1.8			27.9		45	
Hexachlorobenzene								
1,1,1-trichloroethane			306					
1,1-dichloroethane			3.67					
2,4,6-trichlorophenol								
p-chloro-m-cresol								
Chloroform				18.05				
2-chlorophenol								
1,2-dichlorobenzene			2.0					
1,4-dichlorobenzene								
1,2-Trans-dichloroethylene								
1,2-dichloropropane								
1,2-dichloropropylene				0.89				
Ethylbenzene					4.9		0.7	3,018
Methylene chloride[b]						24		
Dichlorobromomethane				1.54				89.3
Naphthalene	92.9		1.5	22			309	
2-nitrophenol								
4-nitrophenol								
N-nitrosodiphenylamine								
N-nitrosodi-n-propylamine								
Pentachlorophenol	6.9		1.6					
Phenol	12.4		0.7				34	
Bis(2ethylhexyl) phthalate	305		14.0	140	5.3	9.5	218	2
Di-n-butyl phthalate		58.4				(5.7)		
Diethyl phthalate			6.1					
Dimethyl phthalate					12.9			
Anthracene						0.2		

TABLE 29 (continued)

Priority pollutant	Concentration, g/L Plant B Influent	 Plant B Secondary effluent	 Plant C Influent	 Plant C Secondary effluent	 Plant E Influent	 Plant E Secondary effluent	 Plant H Influent	 Plant H Secondary effluent	 Plant J Influent	 Plant J Secondary effluent
Pyrene		0.3				0.1				0.1
Tetrachloroethylene			26.4							
Toluene	3.74		236	2.6	61.1	5.5	25.7	11.9	36.1	8.0
Trichloroethylene			17.8		2.0					
α-BHC										0.31
Antimony			7	4	8	8	4	6	7	
Arsenic				1.6						
Beryllium				1.5						
Cadmium	1		5	6	6	1				
Chromium	12	4	35	3	11	4	4		48	25
Copper	74	30	8	20	840	30	22		2,400	100
Cyanide	17		7	13						
Lead	0.9	0.6	120	120	8				29	
Mercury				0.7						
Nickel			150	140	40	40	14		97	90
Silver				(80)	7		41		60	
Zinc	300	170	74	120	7,900	5,100	3,900	960	2,100	800
Other metals:										
Aluminum	160	24	300	190	28	38	93	55	950	10
Barium	37	8	83	73	15	12			100	24
Boron	70	43	39	15	2,360	1,060				
Calcium	20	12	5,000	4,500	5,400	39,000	1,300	6,200	4,900	5,200
Cobalt	5.6	5.2	8.1	5.6			5.4		8.4	0.9
Iron	320	270	1,000	220	120	620	160	400	700	520
Magnesium	9,500	4,670	3,900	730	2,500	3,100	2,600	3,200	5,800	6,900
Manganese	93	59	29	17	27	100	13	9	50	50
Molybdenum			19	24		19	11		4.3	
Sodium	>100,000	>100,000	>100,000	>100,000	>100,000	>54,000	>100,000	>100,000	>100,000	>100,000
Silicon	4,400	2,300	16,000	15,000	11,000	8,600	17,000	15,000	18,000	17,000
Tin	18	41	10	120	30	10	19	55	30	50
Phosphorus	12,000	6,500	4,000	4,100	1,900	1,400	390	200	3,300	600
Titanium	3.9		20	12	18	12	9		1,500	60
Vanadium	58	30	290	400	19	21	35	32	13	11

Priority pollutant	Concentration, μg/L Plant K Influent	 Plant K Secondary effluent	 Plant M Influent	 Plant M Secondary effluent	 Plant U Influent	 Plant U Secondary effluent	 Plant V Influent	 Plant V Secondary effluent	 Plant Z Influent	 Plant Z Secondary effluent
Pyrene										
Tetrachloroethylene										12.0
Toluene	29.3	24.0		0.4		13.0	8.4	1,401	5.5	110.6
Trichloroethylene		4.6						(0.7		
α-BHC		0.31								
Antimony	3	8	0.8	4	7	1		4	11	12
Arsenic	6							4		
Beryllium							5			
Cadmium	4				27	14	4	3		
Chromium	190	4	9	5	40	23			97	50
Copper	260	15					230	170		
Cyanide						212	6	18		
Lead	130				0.4					
Mercury					8				110	
Nickel	100									
Silver	130									
Zinc	150	110	1,200	410	260	190	460	340	110	370
Other Metals:										
Aluminum	280		330	9	900	170	200	160	23	
Barium	28	18	13		10	6	14	13		
Boron	13,000	1,100	910	530	32	280	3,400	480	12	36
Calcium	5,800	3,600	9,700	8,800	5,800	8,000	3,200	3,600	2,500	2,100
Cobalt	9	7	7.7	4.5	5			4	9	6
Iron	670	88	180	60	680	300	370	470	160	75
Magnesium	4,200	3,700	6,700	6,400	2,500	2,500	1,400	1,700	650	1,200
Manganese	38	11	34	140	76	16	63	72	14	10
Molybdenum	20	0.6								
Sodium	>100,000	>100,000	>100,000	>100,000	>100,000	>100,000	>94,000	>100,000	>100,000	>100,000
Silicon	23,000	15,000	15,000	14,000	3,200	3,000	4,500	4,500	8,800	6,200
Tin	50	40	4,000	3,500	28		13	5		
Phosphorus	1,900	930	3,990	3,460	3,500	3,700	750	780	1,100	500
Titanium	3.5	10.4	9.2		6	3	3	1.4	2	
Vanadium	12	35	42	37	23	19	19	13	89	86

[a] Data from reference 35.

Note: Blanks indicate data not available.

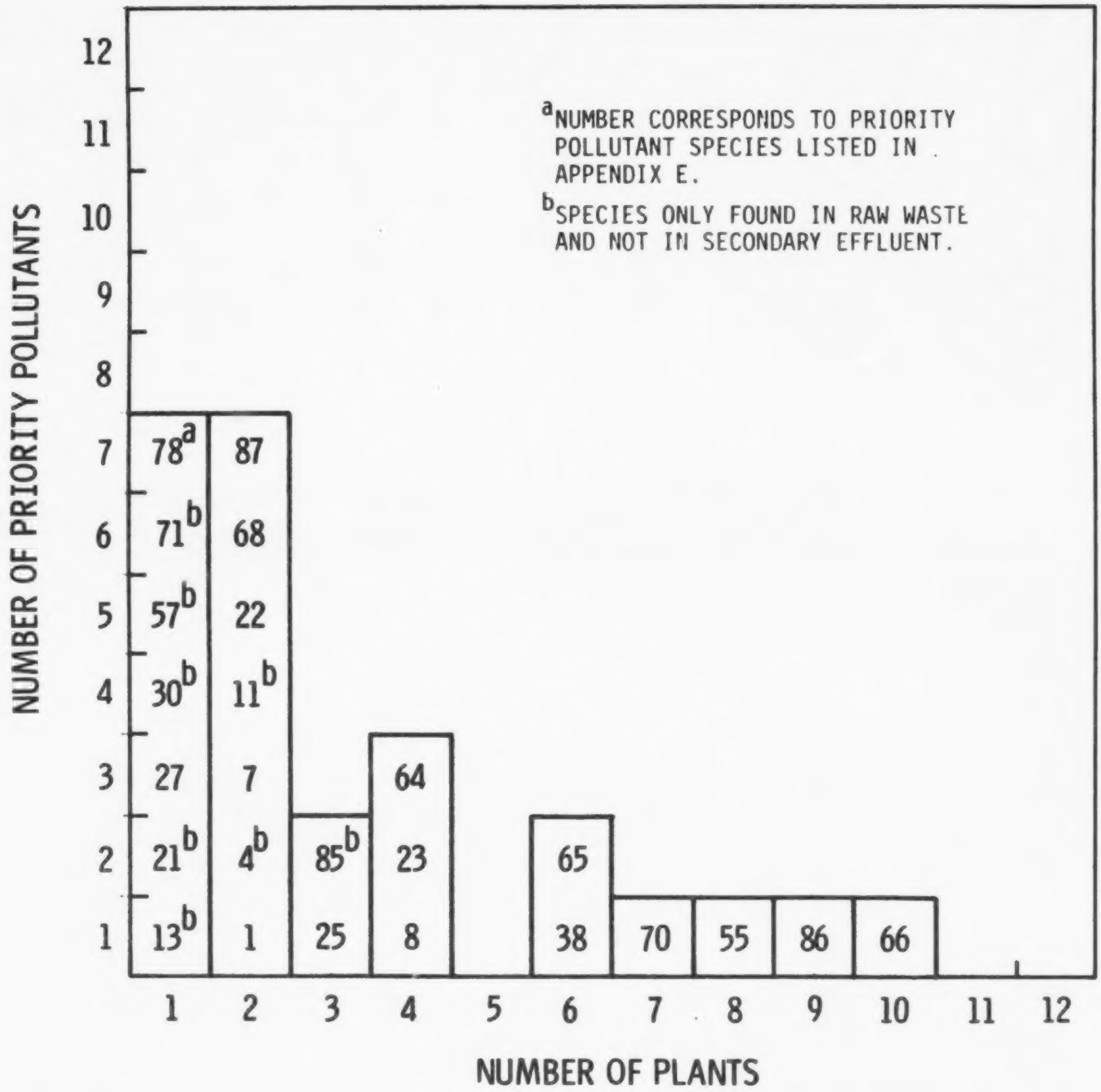

Figure 9. Appearance of organic priority pollutants in the raw wastewater of 10 woven fabric finishing plants [34].

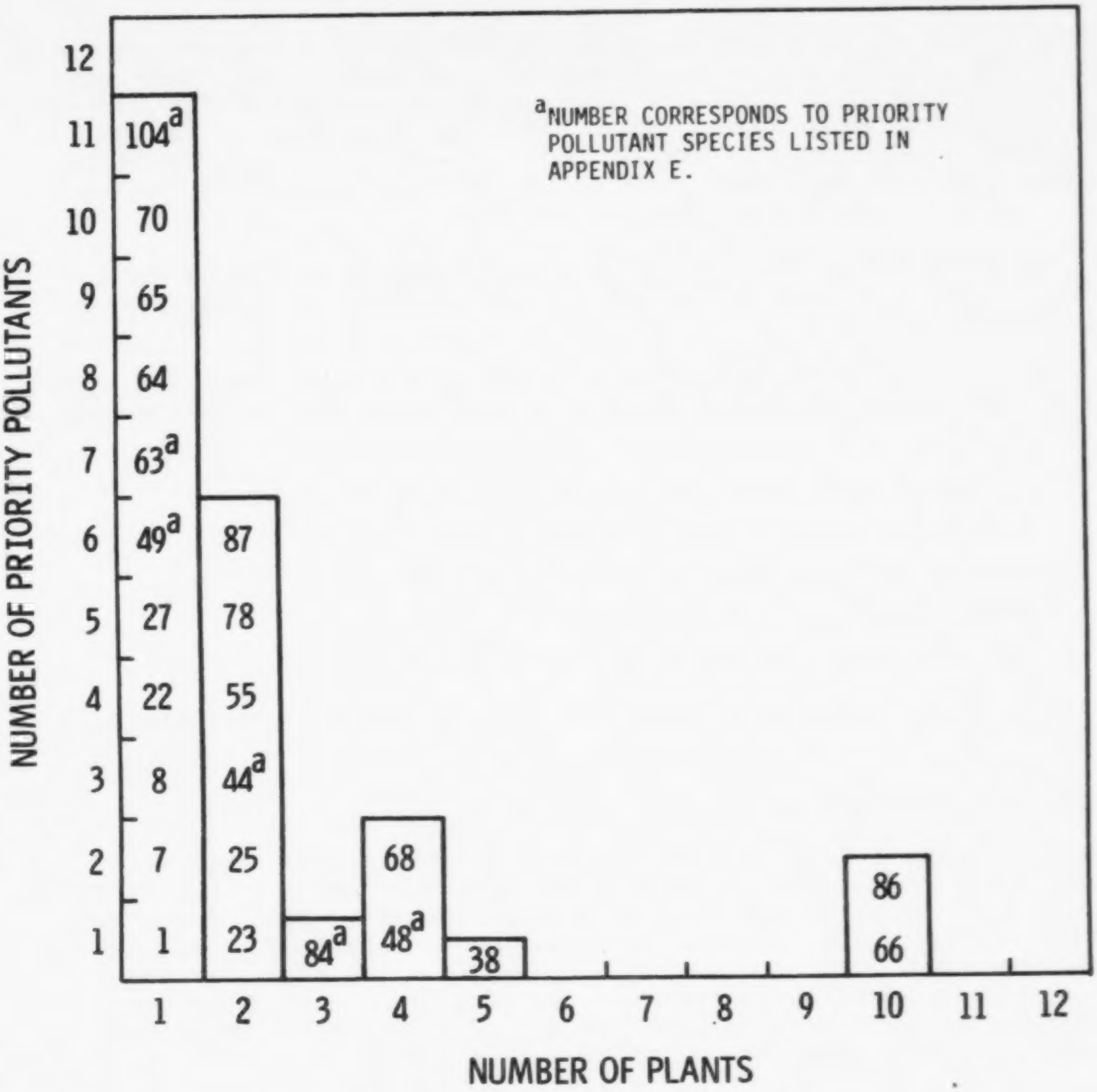

Figure 10. Appearance of organic priority pollutants in the secondary effluents of 10 woven fabric finishing plants [34].

discharge are quantified and then combined to determine another parameter called the source severity. The three factors necessary in determining source severity are:

- Hazard potential of the waste
- Discharge quantities
- Type of receiving body

Hazard Potentials

Hazard factors were developed to correspond to a concentration of pollutant in the receiving stream that is potentially hazardous to aquatic life or human health. They were selected first from water quality criteria if those data were available. In the absence of such criteria other data on health or toxic effects, along with a safety factor to allow for more sensitive species, were used to calculate a hazard factor.

In Appendix F the seven equations are listedthat can be used in determining a hazard factor when water quality criteria are not available.

Appendix G lists the pollutants found in the secondary effluent of 10 woven fabric finishing plants and provides the following data:

- Toxicological data used to derive hazard factors
- Equations used to derive hazard factor
- Hazard factors used in prioritization
- References
- Any necessary comments or clarifications

As more data become available the hazard factor used in this report may be revised.

Discharge Quantities

Discharge quantities are determined by multiplying wastewater flow rates and effluent concentrations. Discharge quantities are calculated to give a maximum discharge quantity and an average discharge quantity. This, along with other factors, were used in calculating a worst-case source severity and a mean (average) case source severity, respectively. Other values of source severity can be generated by the use of different flow rates, concentrations, and receiving body flow rates.

Receiving Body

Potential environmental effects are strongly dependent upon the type and flow rate of the receiving stream. The types of receiving bodies encountered in this report are tributaries, rivers, lakes, and estuaries. The minimum and mean flow rates, when applicable, for the 10 woven fabric finishing plants were collected. These data were obtained by using a map to locate the river nearest a specific plant for which flow rates were provided. Water resource data for specific states published by the U.S. Geological Survey, Water Resources Division [36-39].

The minimum and mean flow rates were used in calculating a worst- and mean-case source severity, respectively, for the 11 woven fabric finishing plants. The receiving body flow rate that was used in calculating a worst- and mean-case source severity for the general overview of woven fabric finishing plants were the minimum and the averages of the mean receiving body flow rates of the 1) woven fabric finishing plants.

Source Severity

Source severity compares the concentration of a given pollutant in the receiving water as a result of discharge, to the concentration of the pollutant. There are two basic equations used in calculating source severity in water corresponding to the two categories of receiving bodies of water:

- Flowing streams where the discharge quantity is compared to the receiving body flow rate times the hazard factors

$$S_e = \frac{U_D C_D}{V_r F} \qquad (10)$$

- Lakes and estuaries where the discharge concentration is compared to the hazard factor:

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[36] Water Resources Data for Georgia, 1977. USGS/WRD/HD-78/051 (PB 287 732). U.S. Geological Survey, Water Resource Division. Doraville, Georgia. 1977. 283 pp.

[37] Water Resource Data for South Carolina, 1975. USGS/WRD/HD-76/004 (PB 251 855). U.S. Geological Survey, Water Resources Division, Columbia, South Carolina, 1975. 219 pp.

[38] Water Resources Data for Massachusetts and Rhode Island, 1977. USGS/WRD/HD-78/020 (PB 284 977). U.S. Geological Survey, Water Resources Division, Boston, Massachusetts, 1977. 323 pp.

[39] Water Resources Data for New Hampshire and Vermont, 1975. USGS/WRD/HD-76/057 (PB 262 800). U.S. Geological Survey, Water Resources Division, 1975. 193 pp.

$$S_e = \frac{C_D}{F} \qquad (11)$$

where S = source severity for a particular pollutant
V_D = wastewater effluent flow rate, m^3/s
C_D = concentration of particular pollutant, g/m^3
V_R = volumetric flow rate of receiving body above plant discharge, m^3/s
F = hazard factor for particular pollutant, g/m^3

However, for pollutant species that deplete the dissolved oxygen content of receiving streams, a different approach was required. First, an excess oxygen demand hazard factor, F_O, is defined as

$$F_O = C_S - DO \qquad (12)$$

where C_S = saturated dissolved oxygen concentration of the receiving stream = 10.2 g/m^3 (assumed for river water at 15°C) [40]
DO = dissolved oxygen freshwater quality criterion = 5 g/m^3 [41]

Also, the concentration (C_D) in Equation 10 and 11 must be expressed as the total oxygen demand (TOD). Since the oxygen demand of the wastewater in the effluent streams of woven fabric finishing plants are expressed as BOD and COD, relationships between TOD, COD, and BOD were needed.

Correlations between TOD, COD, and BOD for municipal waste were obtained by Monsanto Research Corporation. These correlations are

$$TOD = 1.3\ COD \qquad (13)$$

$$TOD = 2.9\ BOD \qquad (14)$$

The relationship between TOD, COD, and BOD will not be valid for all types of wastes. However, these correlations were used for this document.

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[40] Chemical Engineers' Handbook, Fifth Edition. J. H. Perry and C. H. Chilton, eds. McGraw-Hill Book Company, New York, New York, 1973. pp. 3-98, 14-3.

[41] Reznik, R. B., E. C. Eimutis, J. L. Delaney, S. R. Archer, J. C. Ochsner, W. R. McCurley, and T. W. Hughes. Source Assessment: Prioritization of Stationary Water Pollution Sources. EPA-600/2-78-004q, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 1978.

Since the values obtained for TOD by way of COD and BOD differed by more than 50%, both methods of calculating TOD were used in determining the oxygen demand source severity.

Conventional and nonconventional pollutant source severities are presented in Table 30 for the overview of woven fabric finishing, and in Table 31 (next page) for the 11 woven fabric finishing plants. In general, the worst-case source severity was calculated by using the maximum concentration, the maximum discharge, and the low receiving body flow rate. The mean case source severity was calculated by using the mean concentration, the mean discharge rate, and the mean receiving flow rate (from Tables 27-29).

TABLE 30. GENERAL WOVEN FABRIC FINISHING SOURCE SEVERITY FOR CONVENTIONAL AND NONCONVENTIONAL POLLUTANTS

Pollutant parameter	C_D, g/m^3 Maximum	C_D, g/m^3 Mean	Source severity[a] Worst case	Source severity[a] Mean case
Total oxygen demand (TOD)				
By way of BOD[b]	700[b]	100	66	0.009
By way of COD[c]	1,900[c]	420	180	0.037
TSS	280	55	1.8	<0.001
Oil and grease	22	12	940	0.54
Phenol	0.55	0.073	270	0.033
Chromium	19	0.52	180	0.047
Sulfide	2.6	0.43	660	0.096

[a] Maximum and mean discharge flow rates (V_D) that were used: 0.334 m^3/s and 0.0300 m^3/s, respectively. Minimum and mean receiving stream flow rates (V_R) that were used: 0.425 m^3/s and 66.8 m^3/s, respectively.

[b] TOD = 2.9 BOD.

[c] TOD = 1.3 COD.

Source severities for priority pollutants and other metals are presented in Tables 32 and 33 (pages 70 and 71), respectively, for the 10 woven fabric finishing plants.

Other Considerations

Source severity was calculated to give a worst-case (generally; maximum concentration, maximum discharge flow rate, and minimum receiving stream flow rate) and a mean-case (generally; mean

TABLE 31. CONVENTIONAL AND NONCONVENTIONAL POLLUTANT SOURCE SEVERITY FOR 10 WOVEN FABRIC FINISHING PLANTS

Plant	Receiving stream flow rate, Vr, m^3/s		Oxygen demand source severity				TSS		Phenol		Chromium		Sulfide	
			By way of BOD_5		By way of COD									
	Minimum	Mean	Worst case[a]	Mean case[b]	Worst case	Mean case	Worst case	Mean case	Worst case	Mean case	Worst case	Mean case	Worst case	Mean case
B	0.425	5.126	2.9	0.099	8.6	0.44	0.44	0.012	2.3	0.12			15	0.82
C	13.02	22.57	1.0	0.015	6.1	0.94	0.59	0.057	0.34	0.17	0.031	0.012	172	48
E	-[c]	-[c]	2.3		20		0.033		0.61				<500	
H	24.55[d]	114.00[d]	0.26	0.024	1.3	0.14	0.51	0.0043	0.22	0.03	0.0024	<0.001	0.58	0.043
J	0.68	1.86	15	2.4	84	15	5.0	0.23	5.7	2.8			490	98
K	8.10	68.70	0.17	0.01	2.8	0.15	0.014	<0.001	0.33	0.27	0.014	0.001	9.1	0.75
M	6.31[d]	179.13[d]	0.67	0.014	22	0.29	1.3	0.012	2.8	0.064			28	0.14
U	-[c]	-[c]	150	30	1,400	380	30	7.1	90	20	0.94	0.22	1,750	
V	-[c]	-[c]	9.5	6.7	54		2.4	1.9	90	90	0.48	0.34	0.500	
Z	7.36	28.86	0.38	0.038	1.2	0.15	0.123	0.0067	1.3	0.24	0.011	0.001	76	16

Note: Blanks indicate data not available.

[a] Worst case source severity generally used maximum concentration, maximum discharge flow rate, and the minimum river flow rate.

[b] Mean case source severity generally used the mean concentration, mean discharge flow rate, and the mean river flow rate.

[c] Empties into a lake or estuary.

[d] Gaging station more than 30 miles away.

TABLE 32. SOURCE SEVERITY VALUES GREATER THAN 0.001 FOR THE ORGANIC PRIORITY POLLUTANTS IN EFFLUENTS FROM 11 WOVEN FABRIC FINISHING PLANTS

	Source severity value by pollutant							
	1,2,4-trichlorobenzene		Ethylbenzene		Naphthalene		Pentachlorophenol	
Plant	Worst case	Mean	Worst case	Mean	Worst case	Mean	Worst case	Mean
B								
C	0.003	0.001						
E								
H								
J			0.019	0.004				
K								
M	0.003	0.001						
U					0.003	<0.001		
V								
Z			0.036	0.007				

Note: Blanks indicate pollutant not detected or the source severity is <0.001.

concentration, mean discharge, and mean receiving stream flow rate) source severity. However, it is possible to calculate other source severity values using different combinations which would give values between the worst-case source severity and mean-case source severity and below the mean-case source severity. Since the reporting of all these values would lead to confusion, a range was chosen that would give a good indication of the actual source severity for woven fabric finishing plants. This value was the worst-case and mean-case source severity.

CONTROL TECHNOLOGY

Two basic approaches to reduce effluent pollutant concentrations and conserve water in woven fabric finishing plants are in-plant measures and end-of-pipe treatment.

In this section a brief discussion of in-plant measures is given followed by a discussion of end-of-pipe treatment.

In-Plant Measures

The in-plant controls and process changes practiced by woven fabric finishing plants can be described under five basic sections:

- Water reuse
- Water reduction

TABLE 33. SOURCE SEVERITY VALUES GREATER THN 0.001 FOR METALS FOUND IN EFFLUENTS FROM 10 WOVEN FABRIC FINISHING PLANTS

	Source severity by plant											
	B		C		E		H		J		K	
Metal	Worst case	Mean	Worst case	Mean	Worst case	Mean	Worst case	Mean	Worst case	Mean	Worst case	Mean
Aluminum	0.018	0.001	0.015	0.007			0.002	<0.001	0.027	0.005		
Antimony			0.006	0.003								
Boron	0.009	<0.001			1.4	0.5					0.027	0.002
Cadmium			0.01	0.004								
Calcium			0.011	0.005	4.9	2.0						
Chromium	0.012	<0.001	0.002	<0.001	0.08	<0.001						
Cobalt	0.097	0.005							0.06	0.01		
Copper	0.004	<0.001							0.05	0.01		
Iron	0.13	0.007	0.012	0.006	2.1	0.8	0.009	0.001	0.95	0.19		
Lead			0.04	0.01								
Mercury	0.045	0.002	0.006	0.003								
Magnesium	1.3	0.07	0.11	0.05	6.0	2.8	0.04	0.006	4.4	0.89	0.13	0.01
Manganese	0.18	0.01							0.55	0.11		
Nickel			1.7	0.78								
Phosphorus	980	53	65	30	1,400	800	1.3	0.2	330	66	17	1.4
Silver			0.026	0.012								
Tin			0.19	0.087					2.7	0.55	0.073	0.006
Zinc	0.005	<0.001							0.088	0.017		

(continued)

	Source severity by plant							
	M		U		V		Z	
Metal	Worst case	Mean	Worst case	Mean	Worst case	Mean	Worst case	Mean
Aluminum	0.004	0.001<	0.84	0.05	0.018	<0.001		
Antimony			0.004	<0.001				
Boron	0.058	0.002	0.37	0.04	0.97	0.04		
Cadmium								
Calcium								
Chromium			0.28	0.005	0.086	0.002		
Cobalt					0.5	0.008	0.019	0.003
Copper			0.02	0.005	0.17	0.05		
Iron					1.6	0.6		
Lead								
Mercury								
Magnesium	1.0	0.03	4.8	2.0	4.2	1.6	0.042	0.008
Manganese	0.23	0.006	0.32	0.005				
Nickel								
Phosphorus	280	7.4	3,700	1,500	1,200	800	9.0	1.8
Silver								
Tin								
Zinc	0.007	<0.001	0.038	0.002	0.068	0.002		

Note: Blanks indicate metal was not detected or the source severity was <0.001.

- Chemical substitution
- Material reclamation
- Process changes and new technology

Reported in-plant control measures for 81 woven fabric finishing plants are presented in Table 34.

TABLE 34. REPORTED IN-PLANT CONTROL MEASURES FOR WOVEN FABRIC FINISHING PLANTS [2]

In-plant control measures	Number of plants	Percent of total plants
Water reuse	28	34.6
Water reduction	20	24.7
Chemical substitution	17	21.0
Material reclamation	16	19.8
Total	81	100

Water Reuse--
Water reuse in-plant measures are those situations which reduce hydraulic loadings to treatment systems by using the same water in more than one process. The recycling of water from advanced wastewater treated waste is not considered an in-plant measure in this section. The two major water reuse measures practiced which can lead to substantial energy and water savings are (1) reuse of relatively clean cooling water, and (2) reuse of process waste from one operation in a second unrelated operation.

Of 81 woven fabric finishing plants surveyed, 34% were found to have instituted some form of water reuse [2].

Water Reduction--
Water reduction, as the name implies, is the use of less water in textile mill operations. The three forms of water reduction are: (1) use of countercurrent flow washing, (2) "good housekeeping" and conservation measures, and (3) process modifications. Of the 81 woven fabric finishing plants surveyed 25% have instituted forms of water reduction [2].

Chemical Substitution--
Chemical substitutions involves replacing chemicals having high pollutant strength or toxic properties with others that are less polluting or more amenable to wastewater treatment. This type of control can play an important role in the future as discharge control standards are developed or made more stringent.

Of the 81 woven fabric finishing plants surveyed, 21% were found to practice some measure of chemical substitution [2].

Material Reclamation--
At the present time, material reclamation measures are often implemented to reduce processing costs, reduction of pollutant loadings being a secondary benefit. An example commonly practiced in textile plants is caustic recovery after mercerizing. It is anticipated that chemical and wastewater treatment costs will make material reclamation a more practiced in-plant measure in the future.

Of the 81 woven fabric finishing mills, 20% practiced forms of material reclamation [2].

Process Changes and New Process Technology--Process changes and new process technology comprises a group of related measures that may be used to achieve benefits in the four areas already noted. Changes in both processes and material flow procedures give a feasible method of reducing hydraulic and pollutant loadings in the textile plants at the present time. New process technology also holds great promise for reducing hydraulic and pollutant loads in textile plants [2].

End-of-Pipe Treatment--End-of-pipe treatment is dealt with in two sections: present best practicable technology (BPT), and advanced wastewater technology.

Present Best Practicable Technology

A summary of current end-of-pipe treatment practices by the woven fabric finishing plants is given in Table 35 (next page) for both direct and indirect dischargers.

The table illustrates that for the direct dischargers, 11% provide no wastewater treatment, 9.8% provide only preliminary treatment (i.e., neutralization, screening, equalization, heat exchange, disinfection, primary sedimentation, and/or flotation), 73.2% provide biological or an equivalent level of treatment (i.e., aerated or unaerated lagoons, biological filtration, activated sludge, and chemical coagulation/flocculation without preceding biological treatment), and 6.1% provide an advanced level of treatment (i.e., activated carbon, chemical coagulation following biological treatment, ozonation, filtration, ion exchange, and membrane processes). For the indirect dischargers, 57.1% provide no treatment, 29.0% provide preliminary treatment, 10.3% provide biological or an equivalent level of treatment, and no plants provide an advanced level of treatment [2].

Woven fabric finishing plant treatment facilities that provide the BPT (treatment facilities which can meet the 1977 discharge limits for criteria pollutants) usually include the following:

TABLE 35. SUMMARY OF CURRENT END-OF-PIPE WOVEN FABRIC FINISHING TREATMENT PRACTICES FOR DIRECT AND INDIRECT DISCHARGERS [2]

Treatment description	Direct dischargers	Indirect dischargers	Unclassified dischargers	Total number of mills
No treatment	9	128	NA[a]	137
Preliminary[b]	8	65	NA	73
Biological or equivalent[c]	60	23	NA	83
Advanced[d]	5	0	NA	5
Treatment unclassified	0	8	30	38
Totals	82	224	30	336

[a] Does not apply.

[b] Neutralization, screening, equalization, heat exchange, disinfection, primary sedimentation, and/or flotation.

[c] Aerated and unaerated lagoons, biological filtration, activated sludge, chemical coagulation/flocculation without preceeding biological treatment.

[d] Activated carbon, chemical coagulation following biological treatment, ozonation, filtration, ion exchange, membrane processes, etc.

(1) screening, (2) equalization, (3) neutralization, (4) activated sludge, (5) chemical coagulation, and (6) sedimentation (secondary clarification). A model schematic of woven fabric finishing wastewater treatment meeting 1977 BPT limitations is provided in Figure 11 (next page).

Specific quantitative information about the treatment technologies employed by woven fabric finishing plants is presented in Table 36 for both direct and indirect dischargers. Over 50% of the direct dischargers provide screening (70%) activated sludge (71%), and secondary sedimentation (73%); while less than 50% provide equalization (38%), neutralization (23%), and chemical coagulation (14%). These six treatment technologies are briefly discussed below [2].

Screening--
Screening is usually the first operation employed in wastewater treatment. It is used to remove large suspended particles, such as dirt, fibers, and undissolved chemicals from the textile wastewater. Of the 56 direct dischargers in the survey 70% were found to provide certain types of screening [2].

Equalization--
Equalization is most often practiced as an initial treatment step to provide nearly uniform hydraulic, organic, and solids loading

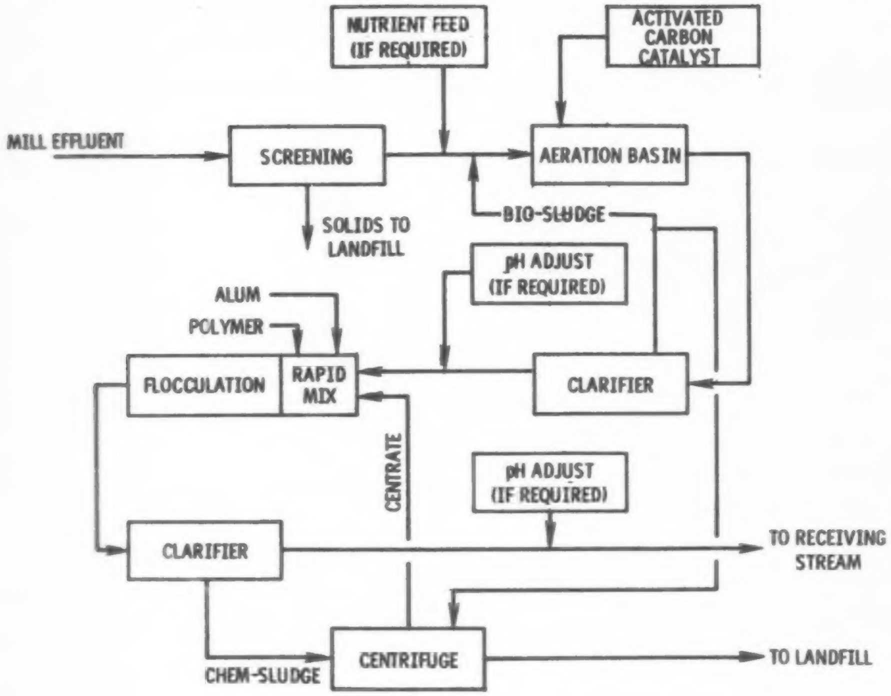
NUTRIENT FEED (IF REQUIRED)
ACTIVATED CARBON CATALYST
MILL EFFLUENT
SCREENING
AERATION BASIN
SOLIDS TO LANDFILL
BIO-SLUDGE
pH ADJUST (IF REQUIRED)
ALUM
POLYMER
FLOCCULATION
RAPID MIX
CLARIFIER
CENTRATE
pH ADJUST (IF REQUIRED)
CLARIFIER
TO RECEIVING STREAM
CHEM-SLUDGE
CENTRIFUGE
TO LANDFILL

Figure 11. Woven fabric finishing wastewater treatment model schematic meeting 1977 (BPT) limitations [5].

rates to subsequent physical unit operation and chemical and biological unit processes, so that these operations are more efficient. Of the 56 woven fabric finishing direct dischargers, 38% provided equalization [2].

Neutralization--
Neutralization is the process of adjusting the pH so that the waste is within acceptable limits for discharge to a receiving body or subsequent treatment plant operation. A pH range of 6.0 to 9.0 is usually considered acceptable. Of 56 direct discharge plants surveyed, 23% provided neutralization as part of their wastewater treatment facility [2].

Activated Sludge--
The activated sludge process is an aerobic biological process, of which many variations exist. The general method employed is to treat the waste with a sludge or suspension of microorganisms, aerate the mixture, then separate the sludge by sedimentation [2]. The effectiveness of activated sludge in treating woven fabric finishing plants wastewater is demonstrated by Table 37 for plants for which historical data was available. BOD removal

TABLE 36. SPECIFIC QUANTITATIVE TREATMENT TECHNOLOGY INFORMATION EMPLOYED BY DIRECT AND INDIRECT WOVEN FABRIC FINISHING DISCHARGERS

Woven fabric finishing	No. of mills	Physical						Biological					Chemical			Tertiary		Other
		Sc	Eq	1°	2°	Sk	Fi	AS	Al	A2	An	TF	Ne	CC	Ox	Ac	PC	
Indirect dischargers pretreatment	46	25	23	2	3	0	1	1	6	3	0	0	8	4	1	0	0	3
Direct dischargers treatment	56	39	21	4	41	0	2	40	13	16	0	2	13	8	19	1	0	9

Note:
Sc = Screening
Eq = Equalization
1° = Primary sedimentation
2° = Secondary sedimentation
Sk = Skimming
Fi = Filtration
AS = Activated sludge
Al = Aerated lagoon
A2 = Facultative or tertiary lagoon
An = Anaerobic lagoon
TF = Trickling filter
Ne = Neutralization
CC = Chemical coagulation
Ox = Oxidation, including disinfection
AC = Activated carbon
PC = Powdered activated carbon

TABLE 37. DEMONSTRATED REMOVAL EFFICIENCIES OF ACTIVATED SLUDGE FOR BOD, COD, AND TSS

Plant	Average flow, MGD	Basin volume, MG	HP/MGD	Detention,[a] hr	BOD, mg/L		Percent removal	COD, mg/L		Percent removal	TSS, mg/L		Percent removal
					Influent	Effluent		Influent	Effluent		Influent	Effluent	
B	0.82	3	107	88	399	19.5	95.1	1,033	214	79.3	27	24	11.1
C	3.13	10	41	76.7	280	20.2	92.8	1,025	412	59.8		97.6	
E[b]	2.17	3.8	79	42.0									
H	2.26	7.2	62.5	76.5	380	26	93.2	1,093	397	63.7	65	57	12.3
J	3.71	40	45	259	542	24	95.6	1,716	375	78.1	233	34	85.4
K	2.0	14	57	168	361	7.4	97.8		181.4		74	8	89.2
M	8.13	15	120	44.3	707	10.4	98.5	2,023	525.6	74.0	125.6	63.5	49.4
R[b]		40	20	417	715	36	95	1,082	233	78.5	171	57	66.7
U	0.33	2.4	125	175	342	38	88.9	1,604	899	44.0	75[b]	40[b]	46.7
V	0.33	6	38	436		4 7		113			20.8		
Z	2.03	10.5	57	124		7 2	594	137	75.3		42		

Note: Blanks indicate data not available.

[a] Calculated based on average flow rate and basin volume.

[b] Data from Reference 33.

ranges from 88.9% to 98.5%, for COD the range is from 44.0% to 79%, and for TSS the range is from 11.1% to 89.2%. Of 56 woven fabric finishing direct dischargers, 71.4% employed activated sludge in their treatment facility.

Chemical Coagulation--
Coagulation is the process by which chemicals are employed to destabilize suspended material found in woven fabric finishing plants waste such that the particles contact and agglomerate. Flocculation, the next step in the process, then promotes interparticle contact to form a floc. This floc is then removed by sedimentation. Of the 56 woven fabric finishing direct dischargers, 14% practiced chemical coagulation [2].

Sedimentation--Sedimentation, also termed clarification, uses the force of gravity to remove settleable solids from wastewater. Two types of sedimentation performed are primary and secondary sedimentation. Primary sedimentation is not often employed (only 7% of 56 mills) due to the fact that textile wastewaters are generally low in settleable solids. Secondary sedimentation, the most widely employed waste treatment process (73% of 56 mills), is considered an integral part of the activated sludge systems. For this reason, separate performance data are not readily available. A properly designed facility should yield good effluent quality if the biological process is working properly [2, 5].

Advanced Wastewater Technology

Pilot Plant Studies--
A joint research effort has been made by the U.S. Environmental Protection Agency (EPA) and the American Textile Manufacturers Institute (ATMI) to determine the best available technology economically achievable (BATEA) for textile plant wastewaters. Mobile pilot plant studies during 1977 and 1978 were conducted at 23 textile plants representing eight textile processing categories and having well-operated secondary wastewater treatment facilities to evaluate the effectiveness of alternate advanced wastewater treatment (AWT) technologies. Of these 23 textile plants, 11 were in the subcategory of woven fabric finishing.

The mobile pilot plant tested 5 process technologies considered potential BATEA treatment by the EPA and ATMI. These are:

- Reactor clarifier
- Multimedia filtration
- Granular carbon adsorption
- Ozonation
- Dissolved air flotation

Powdered activated carbon was also considered a potential BATEA treatment by the EPA and ATMI but was tested in the laboratory. Anticipated treatment removal efficiencies of BOD, COD, TSS, grease, and color from textile wastewaters by different unit processes is illustrated in Table 38 (next page). Carbon adsorption is expected to remove up to 40% of the BOD, up to 60% of the COD, up to 40% of the TSS, and up to 90% of the color. Multimedia filtration (mixed media filtration) is expected to remove up to 40% of the BOD and COD, up to 80% of the TSS, and up to 90% of the color. Ozonation is expected to remove up to 40% of the COD, up to 70% of the TSS, and up to 80% of the color. A brief discussion of the five process technologies tested by the mobile pilot plant is presented below.

Reactor/Clarifier--

Reactor/clarifier, also known as a sludge-blanket type clarifier, combines coagulation, flocculation, clarification, and upward filtration in a single unit. As shown in Figure 12, influent wastewater is mixed with coagulants as it is fed to the center chamber where floc is formed. After leaving the mechanically stirred-flocculating compartment of the wastewater under treatment flows appeared through a fluidized blanket where the floc solids are maintained. Clear effluent then flows up and out through a weir at the top of the unit. Reactor/clarifiers have become more popular than "flow through" systems in recent years due to the inherent size reduction, and the fact that the floc volume in a reactor clarifier may be as much as 100 times that in a flow through system [5, 42].

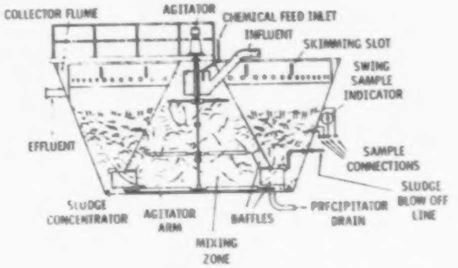
COLLECTOR FLUME
AGITATOR
CHEMICAL FEED INLET
INFLUENT
SKIMMING SLOT
SWING SAMPLE INDICATOR
EFFLUENT
SAMPLE CONNECTIONS
SLUDGE BLOW OFF LINE
SLUDGE CONCENTRATOR
AGITATOR ARM
BAFFLES
PRECIPITATOR DRAIN
MIXING ZONE

Figure 12. Diagram of a reactor clarifier [5].

Multimedia Filtration--

Multimedia filtration units may be either of a gravity or pressure type. Multimedia beds are composed of various combinations of anthracite, sand, activated carbon, and resins. They exhibit a superiority for filtration of activated sludge effluent over other filter bed types. This is due to the high volume of floc storage available in the upper bed and the polishing effect of the small media [5].

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[42] Process Design Manual for Suspended Solids Removal. EPA-625/1-75-003a. U.S. Environmental Protection Agency, Cincinnati, Ohio, January 1975. pp. 6-8.

TABLE 38. ANTICIPATED TREATMENT REMOVAL EFFICIENCIES OF BOD, COD, TSS, GREASE, AND COLOR FROM TEXTILE WASTEWATERS [5]

Treatment unit process	Range of removal efficiency, %				
	BOD_5	COD	TSS	Grease	Color
Primary treatment:					
Screening	0 to 5		5 to 20		
Equalization	0 to 20				
Neutralization					
Chemical coagulation (removals vary with chemicals and dosage used)	40 to 70	40 to 70	30 to 90	90 to 97	0 to 70
Flotation	30 to 50	20 to 40	50 to 60	90 to 98	
Secondary treatment:					
Conventional activated sludge and clarification	70 to 95+	50 to 70	85 to 95	0 to 15	Color removals for biological treatment units not documented
Extended aeration and clarification	70 to 94+	50 to 70	85 to 95	0 to 15	
Aerated lagoon and clarification	60 to 90	45 to 60	85 to 95	0 to 10	
Aerobic lagoon	50 to 80	35 to 60	50 to 80	0 to 10	
Packed tower	40 to 70	20 to 40			
Roughing filter	40 to 60	20 to 30			
Tertiary treatment:					
Chemical coagulation	40 to 70	40 to 70	30 to 90	90 to 97	0 to 70
Mixed media filtration	25 to 40	25 to 40	80		
Carbon adsorption	25 to 40	25 to 60	25 to 40		80 to 90
Chlorination	0 to 5	0 to 5		0 to 5	0 to 5
Ozonation		30 to 40	50 to 70		70 to 80
Advanced treatment:					
Spray irrigation	90 to 95	80 to 90	95 to 98		
Evaporation	98 to 99	95 to 98	99		
Reverse osmosis	95 to 99	90 to 95	95 to 98		

Note: Blanks indicate data not available.

Granular Carbon Absorption--

Activated carbon adsorbs a great variety of dissolved organic materials including many which are nonbiodegradable. The adsorption which takes place is facilitated by the large surface areas on the carbon granules which are attributable to its highly porous structure. Biological degradation also occurring on the carbon granules compliments the adsorption process in removing dissolved organic material [43].

Ozonation--

Ozone, because of its instability, cannot be shipped and must be produced on-site. It is capable of removing color and in reducing the bacterial and viral content of textile mill wastewater. Although ozonation is also capable of reducing the concentration of organics, it is not suitable because of the high dosages often required [2, 5].

Dissolved Air Flotation--

Dissolved air flotation is a physical separation used to separate solid particles from the effluent. Unlike a settling basin, this separation takes place at the surface. When the fine air bubbles introduced in the effluent become attached to the solid particles. This causes them to rise to the surface where they are separated [2].

Based on the five process technologies considered potential BATEA technologies, ATMI, the EPA, and Engineering Science(ES) selected seven treatment systems (called modes) which had the greatest potential of success. These modes are:

Mode A - Reactor/clarifier → multimedia filter
Mode B - Multimedia filter → granular activated carbon columns
Mode C - Multimedia filter → ozonator
Mode D - Ozonator
Mode E - Reactor/clarifier (optional) → multimedia filter → granular activated carbon → ozonator
Mode F - Coagulation → multimedia filter
Mode G - Dissolved air flotation

These seven modes were then evaluated to determine optimum operating conditions for the processes, and to select candidate modes (which did not have to be the same as the seven already mentioned) for performing additional testing [34, 35].

The 1977 BPT guidelines and the proposed BAT guidelines for woven fabric finishing plants are provided in Table 39. For a woven fabric finishing plant just meeting BPT guidelines, removal efficiencies of their treatment facility would have to increase to to meet BAT by 33% for BOD, 67% for COD, and 83% for TSS. The BAT guidelines for phenol, chromium, sulfide, and pH remain the same.

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[43] Process Design Manual for Carbon Absorption. EPA-625/1-71-002a. U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1973. p. iii.

TABLE 39. WOVEN FABRIC FINISHING BPT AND PROPOSED BAT EFFLUENT GUIDELINES AND PERCENT DIFFERENCE [33]

	BPT, g/kg[a]		BAT, g/kg[a]		
Compound	Daily maximum	30-Day average	Daily maximum	30-Day average	Percent difference[b]
BOD_5	6.6	3.3	4.4	2.2	33.3
COD	60	30	20	10	66.7
COD-N[c]	20	10	6.6	3.3	66.5
COD-S[c]	40	20	13.4	6.7	66.5
COD-S/N[c]	60	30	20	10	66.7
TSS	17.8	8.9	3	1.5	83.1
Phenol	0.10	0.05	0.10	0.05	0
Chromium	0.10	0.05	0.10	0.05	0
Sulfide	0.20	0.10	0.20	0.10	0
pH	6-9				

[a] Units given in g/kg except pH - given in pH units.

[b] (BPT - BAT)/BPT values x 100.

[c] Additional COD allowances for the complex manufacture of natural fiber, synthetic fiber, and synthetic/natural blend.

Table 40 (next page) gives the recommended BATEA process for the 11 woven fabric finishing plants for which ATMI and the EPA pilot plant data were available. The BATEA process recommended most often for woven fabric finishing plants was Mode B, multimedia filtration followed by carbon adsorption.

Other Advanced Wastewater Process Technologies--
Hyperfiltration and powdered activated carbon, both advanced wastewater treatment processes, are briefly described on the following pages.

Hyperfiltration--
Hyperfiltration is a physical separation process that relies on applied pressure to force flow through a semipermeable membrane (permeable to water but not dissolved materials of a specific molecular size). The system is capable of removing suspended particles and substantial fractions of dissolved impurities, including organic and inorganic materials. A full-scale

TABLE 40. RECOMMENDED BATEA PROCESS FOR 10 WOVEN FABRIC FINISHING PLANTS

Plant	Recommended BATEA process
B	Multimedia filtration
C	Reactor/clarifier followed by multimedia filtration followed by carbon columns
E	
H	Multimedia filtration with pre-filter coagulation followed by carbon adsorption
J	Multimedia filtration followed by carbon adsorption (Mode B)
K	Multimedia filtration
M	Multimedia filtration followed by carbon adsorption (Mode B)
U	Multimedia filtration followed by carbon adsorption followed by ozonation
V	Multimedia filtration with precoagulation
Z	Multimedia filtration followed by carbon adsorption (Mode B)

demonstration project has been funded by the EPA and is currently in the design and construction phase [2].

Powdered Activated Carbon--
Powdered activated carbon treatment (PACT) refers to the addition of powdered carbon to the activated sludge process. This addition can significantly upgrade effluent quality in conventional activated sludge plants [2].

In the ATMI and the EPA research study, powdered activated carbon treatability tests were performed in the laboratory.

SECTION 6

SOLID WASTES

SOURCE AND NATURE

Studies indicate that the woven fabric finishing segment of the U.S. textile industry produced 37,702 Mg dry weight (1,618,203 Mg wet weight) of solid wastes in 1977 [44]. These wastes consist of process wastes (88% of the total) and wastewater treatment plant sludges.

Sources of solid wastes in the finishing of woven fabrics are (1) waste fiber in short lengths which accumulates on or around machinery or is filtered out in the wastewater treatment system, (2) plant trash which contains discarded cardboard boxes, fabric scraps, etc., (3) dye and chemical containers (bags, cans, and drums) and the residual material they carry, and (4) sludges from wastewater treatment facilities (see Appendix H). Components of these waste streams are heavy metals, dyestuffs and selected chemicals and solvents used in the various dyeing and finishing processes. Among these are acids, alkalies, bleaches, adhesives and polymers, crosslinking agents, conditioners, catalysts, detergents, dye carriers, chemical finishes, and solvents.

Process Wastes

Over 96% (dry weight basis) of the land destined manufacturing wastes are nonhazardous [44]. This includes lint, fibers, cloth, cardboard, and empty containers of nonhazardous chemicals. Discarded dye and chemical containers constitute the major source of potentially hazardous process-related solid wastes, the potentially hazardous component being the residual dyes and chemicals left in a container at the time of disposal.

Discarded dye containers carry approximately 28 g to 56 g of dyestuff [4]. Very little is known about the toxicity of dyes to the human population and so for only 56 of the over 1,000 dyes commercially available have been tested to determine their toxicity to aquatic life forms [44]. In these tests some dyes (basic or cationic dyes, some acid dyes and some disperse dyes) exhibited appreciable toxicities to fish and algae. The remaining dyes are complex refractory organics which may degrade in an anaerobic atmosphere such as a landfill and leach out toxic, carcinogenic, mutagenic, or teratogenic metabolites. Table 41 lists the major dye types used, the percentage of use they receive, and the types of fibers on which they are used.

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[44] Abrams, E. F., D. K. Guinan, and D. Derkies. Assessment of Industrial Hazardous Waste Practices, Textiles Industry. EPA Contract No. 68-01-3178 (PB 258 953). U.S. Environmental Protection Agency, Washington, D.C., June 1975. 276 pp.

TABLE 41. DYE USE BY FIBER TYPE [44]

Dye types	Fiber used on	Total dye use, %
Vat	Cotton, rayon, polyester/cotton	26
Direct	Cotton, rayon, polyester/cotton, nylon/cotton	17
Disperse	Acrylic, acetate, polyester, polyester/cotton, nylon	15
Acid	Wool, nylon	10
Sulfur	Cotton, rayon, polyester/cotton	10
Basic (cationic)	Acrylic, polyester, polyester/cotton, nylon	6
Azoic	Cotton, rayon	3
Fiber reactive	Cotton	1
Fluorescent	Cotton, wool, rayon, polyester/cotton	1
Mordant	Wool	1
Aniline black	Cotton	
Developed	Cotton, rayon	
Blends	Polyester/cotton	
Indigo	Cotton, nylon/cotton	~10
Natural	Cotton	
Oxidation base	Cotton	

Other chemicals contained in bags and drums which must be disposed of when empty include compounds such as dichromate salts (oxidizing agents); sodium hydrosulfite (reducing and stripping agent); zinc nitrate and magnesium chloride (catalysts); polyvinyl chloride, tetrakis (hydroxymethyl) phosphonium chloride, chlorinated paraffins, and organic phosphorus compounds (flame retardants); silico-fluoride compounds, sodium pentachlorophenate, and phenyl sulfonic acid derivatives (moth-proofing agents); and urea-formaldehyde, dihydroxydichlorodiphenylmethane, mixtures of zinc salts of dimethyldithiocarbamic acid, 2-mercaptobenzothiozole, and copper naphthalenes (mildewicides). It has been estimated that about 25% of the chemicals in this waste stream are potentially hazardous [44].

Wastewater Treatment Sludges

Sludges from chemical and biological wastewater treatment processes comprise about 12% of the total solid wastes generated by the woven fabric finishing segment of the textile industry. Sludges are generated by chemical precipitation of dissolved solids, chemical coagulation and subsequent sedimentation of suspended solids, and most commonly, by growth of a biomass (microbial organisms) which feed on dissolved and suspended organic materials in the wastewater stream. Wastewater treatment sludges contain heavy metals, adsorbed dyes and chemicals, and chemical and biological solids. Because of this they are considered to be potentially hazardous making this the major source of such wastes accounting for approximately 80% (dry weight basis) of the potentially hazardous land destined wastes.

In the textile industry the vast majority of wastewater treatment sludges are from some form of aerated biological treatment. These can be classified as either retained or wasted. Retained sludges are those that are so slowly generated by aerated biological treatment of textile wastewaters that there is no need for periodic disposal. This type of sludge is allowed to accummulate in the treatment pond over a period of 5 years to 10 years. Wasted sludge is excess sludge which must be removed and disposed of on a regular basis. About 40% of the plants engaged in woven fabric finishing (accounting for approximately 56% of the total production) find it necessary to dispose of excess sludge [45]. Both retained and wasted sludges are considered to be hazardous because of their potential for contaminating ground water through leaching of hazardous components into the soil.

Heavy metals most likely to be present in the textile sludges and which have been cited as cause for concern are arsenic, cadmium, chromium, cobalt, copper, lead, mercury, and zinc. The bulk of the heavy metals are washed or rinsed from the fabric into the textile mills wastewater treatment system from operations such as scouring of incoming greige goods, dyeing of fabrics, and application of finishes. Other sources of these metals are premetalized dyes (3% to 4% metal content) and some basic dyes requiring preparation as a double salt of zinc (3% metal content), dichromates used to oxidize and fix certain dyes, chromium compounds used in topchroming, various metal salts such as zinc nitrate which are used as catalysts for the application of wash and wear permanent press, or water repellent finishes, heavy metal compounds used to improve wash fastness and light fastness in certain fabrics, metals used in flame-retardant finishes, and from the application of pesticides or other chemicals.

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[45] Frank, A. Textile Mill Sludge Management: Greige Clouds on the Horizon. Sludge, 2(3):21-25, May-June 1979.

Generally iron accounts for about 50% by weight of the heavy metals and zinc for an additional 25% by weight due largely to the use of zinc nitrate as a catalyst in the application of permanent press finishes [4].

Little is known about the nature of organic compounds in textile sludges. In one study, the concentration of chlorinated organics in sludge was monitored and it was found that ∿99% by weight of the total amount was in the solid phase [4]. Concentrations of chlorinated organics in the liquid phase and the suspended solids phase measured at five woven fabric finishing plants, ran from 0.001 ppm to 0.23 ppm and from 1.3 ppm to 39 ppm, respectively [46].

SOLID WASTE DISCHARGE DATA

Estimated quantities of solid wastes generated by the woven fabric finishing industry for the years 1974 and 1977 and projected waste quantities for 1983 are listed in Table 42 [44]. The projected increase is based on a 3% per year growth factor and reflects large increases in sludge volumes expected to result from the issuance of effluent guidelines for the textiles point source category.

TABLE 42. ESTIMATED QUANTITIES OF TOTAL AND POTENTIALLY HAZARDOUS LAND DESTINED WASTES FROM WOVEN FABRIC FINISHING FOR 1974 AND 1977 [44]

Waste type	Waste quantities, Gg/yr	
	1974	1977
Total wastes:		
Dry basis	35.6	37.7
Wet basis	1,522	1,618
Total potentially hazardous wastes:	15.3	16.2
Dry basis	15.3	16.2
Wet basis	1,500	1,600
Total hazardous constituents:		
Dry basis	0.84	0.89

The quantities of solid waste produced per quantity of product (emission factors) for the various waste producing operations are shown in Table 43 [44]. The emission factors in this table can

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[46] Shaver, R. G., and D. K. Guinan. Textile Sludge Characterization. In: Proceedings of the Textile Industry Technology Symposium, Williamsburgh, Virginia. December 1979.

TABLE 43. EMISSION FACTORS FOR SOLID WASTES PRODUCED DURING WOVEN FABRIC DYEING AND FINISHING OPERATIONS [44]

Unit operation	Waste material	Emission factor, kg of waste/Mg of product
Singe and desize	Cloth	0.2
Mercerize	Cloth	0.1
Bleach and wash	Cloth	0.2
Mechanical finish	Cloth	6
	Flock	4
Dye and/or print, applied finish	Dye containers[a]	0.5
	Chemical containers[a]	0.8
Wastewater pretreatment screening	Fiber	0.8 (dry) 2.8 (wet)
Wastewater treatment	Wasted sludge[a]	20 (dry) 2,300 (wet)
	Retained sludge[a,b]	67 (dry) 7,300 (wet)

[a] Waste streams considered to be potentially hazardous.

[b] Retained sludge quantities are accumulations over the life of the pond and cannot be directly related to preoduction.

be applied to the description of an average plant found in Section 4 to obtain average emission rates.

Emission factors determined in Reference 44 for the potentially hazardous components of the dye and chemical container waste stream are 0.0023 g/kg of product and 0.04 g/kg of product, respectively. Calculation of emission factors for the individual pollutant species in this stream is not feasible due to the large number of dye and chemical formulations used in the finishing of woven fabrics and a lack of data on (1) the quantities of each type of formulation used, and (2) the chemical composition of each formulation including major and trace constituents.

Woven fabric finishing mills have reported biological sludge volumes ranging from 0.8 L/m^3 to 182 L/m^3 of wastewater treated. The wide range of values reflect differences in aeration detention periods, loading rates, ambient temperatures, etc. The median value for these mills was about 23 L/m^3. For reference purposes this can be compared to an average value of 76 L/m^3 for a conventional activated sludge plant handling domestic wastes [2].

In an earlier assessment conducted for the EPA Office of Solid Waste Management Programs, 20 samples of wastewater treatment sludges from 5 woven fabric finishing plants were analyzed for selected trace metals and total chlorinated organics [44]. The results of these measurements are shown in Table 44 [45].

TABLE 44. WOVEN FABRIC DYEING AND FINISHING-SLUDGE ANALYSES [44]

Parameter	Concentration Range,[a] mg/L	Average,[b] mg/kg dry sludge
Arsenic	<0.6 to <1.4	<11
Barium	12 to 85	39
Cadmium	<1.4 to 10.8	4.4
Chromium	89 to 3,969	1,196
Cobalt	<2.8 to 109	26
Copper	193 to 1,130	652
Iron	917 to 13,600	4,910
Lead	<16 to 68	36
Manganese	42 to 318	128
Mercury	0.1 to 0.7	0.35
Molybdenum	<0.2 to <28	<17
Nickel	12 to 88	32
Zinc	318 to 7,791	2,370
Total heavy metals[c]		9,412
Aluminum	1,420 to 12,800	4,620
Magnesium	1,340 to 5,730	2,820
Potassium	1,420 to 6,350	3,580
Sodium	19,400 to 94,700	51,300
Strontium	2.4 to 21	16
Total chlorinated organics[c]	4.3 to 27.8	15.2
Suspended solids, %	0.42 to 1.34	0.88
Total solids, %	0.72 to 2.04	1.26

[a] Range of the individual plant averages.

[b] Grand average of 20 measurements from five plants.

[c] Less than values were considered to be at the maximum in computing totals.

DISPOSAL METHODS

The disposal of process wastes are handled differently from the disposal of wastewater treatment sludges throughout the textile industry. The major reason for this is the difference in moisture content although other things such as quantities produced, knowledge of waste contents, and the economics involved in disposal of hazardous versus nonhazardous wastes will probably contribute to the continued segregation of these waste streams.

The following subsection describes sludge preparation and disposal techniques which have been used in the past or are currently being used by woven fabric finishing plants. It should be noted that disposal methods used in the future will depend most on the nature of Federal hazardous waste regulations and solid waste disposal criteria.

Predisposal Treatment Practices

Pretreatment of sludges prior to disposal can involve stabilization, wet air oxidation or dewatering, but no pretreatment is currently typical of the industry [4]. It is expected, however, that pretreatment will be used increasingly to meet compliance with sludge management regulations.

Sludge processing generally consists of stabilization and/or dewatering. Stabilization or digestion of the putrescible organic materials in biological sludges reduces the potential for odors and other nuisance conditions and reduces pathogenic bacteria populations, thus increasing the options for ultimate disposal. Dewatering removes excess free water to improve handling characteristics and reduce transportation costs.

The most common sludge stabilization technique is anaerobic digestion. Lagooning of sludges has long been practiced and is the most used method in the textile industry, though the primary purpose is often not stabilization but temporary storage or a means of ultimate disposal. Sludge lagoons are generally not recommended since they are particularly susceptible to odors and nuisance conditions. However, if properly sized and operated, they can stabilize and consolidate sludge with very little attention. Typically, sludge is deposited in a lagoon at depths of 1 m to 2 m [47]. A requirement for thorough digestion is a detention time of approximately three years, with one year without sludge addition [48].

Stabilization may also be accomplished internally within the activated sludge process or other biological process by retaining solids for extended periods. Typical extended aeration systems utilized in the textile industry produce a relatively stable waste sludge whereas sludge from high rate systems may require further stabilization prior to disposal. Internal aeration periods of greater than 48 hours have been regarded as providing full stabilization [2]. This form of aerobic digestion has drifted in and out of favor over the past 20 years. The process is less affected by toxins than anaerobic digestion but energy costs are high and for this reason it is unlikely that aerobic stabilization will become common for textile sludges.

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[47] Donovan, E. J., Jr. Dewatering of Waste Activated Sludge. In: Proceedings of the EPA Symposium on Textile Industry Technology, Williamsburg, Virginia, December 1979.

[48] Bauer, D. J., J. P. Woodyard, and S. P. Shelton. Sludge Treatment and Disposal. In: Proceedings of the EPA Symposium on Textile Industry Technology, Williamsburg, Virginia, December 1979.

Lime stabilization is another technique that has been used for sludge stabilization since it can increase pH until most biological life is destroyed. Quicklime (CaO) also has the ability to dewater sludge through a hydration reaction. This has the advantage of avoiding oxidation reduction reactions which could potentially produce hazardous byproducts. The primary disadvantage to lime stabilization is that the effects are short lived. It has been shown that lime sludges are not chemically stable and that it is impossible to maintain a high pH even with very high dosages. Chemical and/or biological action brings the pH down and odors return.

Wet air oxidation reduces the amount of sludge and makes the remaining sludge easier to dewater. It also converts much of the nonbiodegradable organic material to oxidized innocuous components or biologically degradable material which can be recycled to wastewater treatment.

Only one textile plant is known to have used wet air oxidation but it discontinued this operation in 1972 because it proved to be uneconomical due to the small volume of sludge handled. However, there is a distinct possibility that this procedure may be used in the future because of its ability to treat biologically resistant wastes.

Sludge dewatering is practiced at relatively few textile plants but it is anticipated that it will be used more as sludge volumes increase and disposal options become more limited. Major methods include land drying by the use of sand drying beds or lagoons and mechanical drying with vacuum filters, belt filter presses, pressure filters, and centrifuges. Dewatering by removal of free water from activated sludge produces a sludge of 4% to 6% solids, while removal of bound water by chemical conditioning prior to dewatering results in sludge cakes containing from 12% to 25% solids [47].

Lagoon drying is a low cost dewatering solution. Water drains into the soil or is evaporated. Underdrains may be provided where drainage to ground water is undesirable or soils are not permeable. However, lagoons are susceptible to odors and unsightly conditions. As with other dewatering techniques the sludge must eventually be removed to ultimate disposal.

Sand drying beds require less land than do lagoons but are costly in both capital costs and operating costs due to frequent sludge removal to ultimate disposal.

Mechanical dewatering is used only infrequently in this industry. Currently about three times as many textile plants use sand drying as those using all types of mechanical dewatering systems.

Ultimate Disposal

Textile process wastes are commonly disposed of in onsite landfills or offsite in general purpose landfills though in some cases they may be incinerated with other plant trash. Another method used by some plants for process wastes and occasionally for wastewater treatment sludges is land dumping. This is currently practiced both on site and at local public facilities.

Disposal options frequently practiced for sludges are permanent or semipermanent storage in aeration basins or anaerobic lagoons and landfilling. The majority of textile plants do not routinely waste sludge, but allow it to accumulate in aeration basins. For those that do waste sludge, lagoons are the most common disposal method. Landfilling, when practiced, is currently done both on site and off site with the ratio of on site to off site disposal being about one to one [2]. Other options include landspreading, incineration, and ocean dumping. Though all of these methods have been used in the past, the only one currently being used is landspreading. Due to uncertainties in the potential environmental effects it is being practiced only on a limited basis.

Landspreading is a technique by which wastewater or sludge is mixed with surface soil to achieve volume reduction and degradation. It offers the potential advantages of utilization of the wastes as a fertilizer and minimizing the pretreatment steps required. Provided that adequate suitable land is available, reasonable loading rates are used and the handling of runoff and leachate is adequately addressed in the design, landspreading may prove to be a cost-effective solution to ultimate disposal. The extent to which textile industry sludge is amenable will depend on the specific waste and site characteristics and any applicable regulations promulgated under the Resource Conservation and Recovery Act (RCRA).

There are several steps involved in landspreading including application of waste onto the surface soil, mixing the waste with the soil to aerate the mass and expose the waste to soil microorganisms, possibly adding nutrients or other soil admendments (usually limestone) during site preparation, and remixing the soil/waste mass periodically to promote biodegradation. The sludges are applied to the land by spraying, spreading, or subsurface injection. The field is then disced or plowed by conventional farm equipment. Important processes that contribute to waste volume reduction are microbial degradation, chemical and photochemical degradation, and evaporation and volatilization.

ENVIRONMENTAL IMPACT

In assessing the potential environmental impact of solid waste discharges, the main concern lies with potentially hazardous components which may eventually reach the open environment in food supplies or as water or air pollution. Contamination of food supplies occurs when plants growing around or on waste disposal sites take up hazardous compounds. These plants are in turn ingested by animals and the hazardous materials are passed up through the food chain. Water pollution could result from leaching of heavy metals and hazardous organics into ground water or into runoff which may flow into surface waters. Air pollution results primarily from incineration of solid wastes but also occurs to a much lesser extent during conditioning, transport and land disposal via the mechanisms of wind erosion and evaporation of volatile components.

No information is available on the extent or effects of air and water contamination caused by the disposal of solid wastes from the textile manufacturing industry. Therefore, only a qualitative assessment of the potential effects can be made. The impact of textile sludges on the food chain is most evident when landspreading is used as a disposal technique. Several preliminary assessments have been made in this area on waste sludges similar in character to those produced by woven fabric finishing operations. Tests were conducted on sludge from an integrated denim mill in which landspreading on fields used for sorghum and corn production was done. Preliminary results indicate that the relatively low concentration of heavy metals in the sludge do not pose a threat to human health because of the low levels of plant uptake observed. In another series of experiments, wastewater treatment sludge from an organic chemical plant which produces mostly dyes, dye intermediates, dye carries, and pigments for use in the textile industry was tested. The heavy metal content of this sludge was maintained at low levels (generally less than 5 ppm wet weight) through pretreatment of individual waste streams. The results of greenhouse experiments and three years worth of field tests indicate that the practice of landspreading has some beneficial and no apparent detrimental effects on turf grass production [49].

The impact of solid wastes generated by the textile industry on ground and surface water pollution results from the hazardous components including dyes and other organics and heavy metals. A number of dye types such as anthraquinone disperse dyes, vinyl sulfone reactive dyes, and azo disperse dyes have been shown to exhibit refractory behavior in wastewater treatment systems [44]. It can be concluded that many of these dyes are essentially nonbiodegradable given the aeration and retention times used in conventional treatment and thus are incorporated into the sludge in their original forms. There is little information on the toxicities of dyes to humans but some basic (cationic) dyes, some acid dyes, and some disperse dyes exhibit appreciable toxicities to fish and algae.

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[49] SCS Engineers. Land Cultivation of Industrial Wastes and Municipal Solid Waste: State of the Art Study. Contract No. 68-03-2435, U.S. Environmental Protection Agency, Cincinnati, Ohio, April 1978.

Heavy metal concentrations have been found to exceed drinking water standards in extracts from textile sludges. It is suspected that a sizeable portion of these metals are chelated to dyes and are not free to leach from landfilled sludge until the dyes are degraded.

The impact of air pollution resulting from incineration of textile wastes is assumed to be minimal because only a few plants incinerate a portion of their process wastes, and none are known to incinerate wastewater treatment sludges. This is due to the high cost of environmentally acceptable incineration equipment and fuels. Air emissions from volatilization of the organic components of a waste at a disposal site are dependent on the vapor pressure of the specific compounds present and the rate of movement away from the evaporative surface. The magnitude of the volatilization loss depends on the soil moisture content, chemical and physical properties of the waste and the soil, atmospheric conditions (temperature, wind velocity, relative humidity, etc.) and the disposal method [48]. In landspreading, mixing of the waste with the soil should significantly reduce volatilization loss due to increased adsorbtion of the chemical by soil organic matter and clay, and the decreased vapor pressure of the wastes.

ENVIRONMENTAL CONTROLS

Generally no environmental precautions above standard containment methods are taken in the disposal of potentially hazardous wastes in the textile industry. However, air and water contamination can be and in some instances is controlled by elimination of waste streams or by instituting waste containment practices.

One waste stream that is easily eliminated is the residuals found in empty chemical containers. Two forms of control which receive some usage are the use of returnable drums which go back to the supplier and the washing of containers prior to disposal. When containers are washed the hazardous residuals are flushed to the wastewater treatment system where they add little to the total waste load. Another method of waste stream elimination used for potentially hazardous wastes of an atypical nature found in a small portion of the plants in this category is reclamation of selected solvents.

Several containment methods used for sludges in general, but not known to be in use in the woven fabric finishing segment of the textile industry, are lined lagoons, lined landfills, and landfills with leachate collection and treatment. A potential treatment technique currently in the demonstration phase for selected sludges is fixation, which immobilizes the hazardous components in the sludge prior to disposal. This technology involves the use of chemical additives to solidify the sludge. Application of fixation to textile industry sludges has not yet been demonstrated but if successful, this method would provide the advantages of being able to dispose of a solid, enhancing transportation and disposal options.

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APPENDIX A

MRC AIR SAMPLING PROGRAM

SITE PRESURVEY

A presurvey visit to each plant was conducted about two weeks before the actual sampling took place. At this meeting, MRC personnel (project manager and project engineer) and key plant personnel met to discuss the woven fabric finishing source assessment project and the proposed sampling program. Primary objectives were to select the sampling points, arrange for the use of certain plant facilities, and to design a mechanism for obtaining process information during the sampling operation.

A thorough understanding of the processes and chemicals used for fabric finishing at this plant was necessary for the selection of sampling points. Plant personnel provided a step by step, start to finish description of the specific processes and chemicals used at the plant. Discussions were held on the types and quantities of pollutant species that could potentially be emitted from each process. This was followed by a walk-through tour of the plant and an inspection of the potential sampling sites on the roof. The roof-top inspection served two purposes. First, some of the potential sites could be ruled out due to the placement of fans and other obstructions in the stack. Second, a visual and olfactory inspection of the effluent gas streams gave an indication of which processes would provide a worst-case effluent for the emissions study. As a result of these efforts, sampling points were selected and marked.

Arrangements were made with the plant to prepare the sites in advance by cutting ports in the selected stacks and by scheduling their finishing work so that these processes would be in operation during the time scheduled for sampling. Also arrangements were made to obtain laboratory space, the gases needed to operate the gas chromatograph, a lift truck to move the sampling equipment to the roof area, and the use of plant personnel to help coordinate the sampling effort with the finishing operations and to provide current process information.

SAMPLING PROCEDURES

Air emissions from major sources were sampled with a modified source assessment sampling system (SASS) train to collect particulate, trace element, and trace organic emissions. A field portable gas chromatograph was used to analyze the emissions from these processes for total hydrocarbon emissions, nonmethane total hydrocarbon emissions, and C_1 through C_6 hydrocarbons.

The SASS train normally employs a set of three cyclones and a filter for particulate size fractionation and collection, a solid sorbent trap utilizing XAD-2 resin for organic collection, a set of impingers for the collection of volatile trace elements, and a system for flow measurement and gas pumping. For this study, the train was modified in two ways. First, the cyclone and filter assembly was replaced with a single oversize filter holder and filter (216 mm). This modification, done to simplify the cleanup procedure was deemed acceptable because the processes sampled were expected to have a very low particulate loading. The second modification dealt with the impinger portion of the train. Because meeting the objectives of this study did not require analysis for volatile trace elements, the number of impingers was reduced from four to three and the contents were changed from those specified in the IERL-RTP Level I Procedures Manual [50]. This modification served to simplify the preparation and cleanup of the train and the analytical workup for the determination of the nonvolatile trace elements. A schematic of the SASS train as modified for this program is shown in Figure A-1.

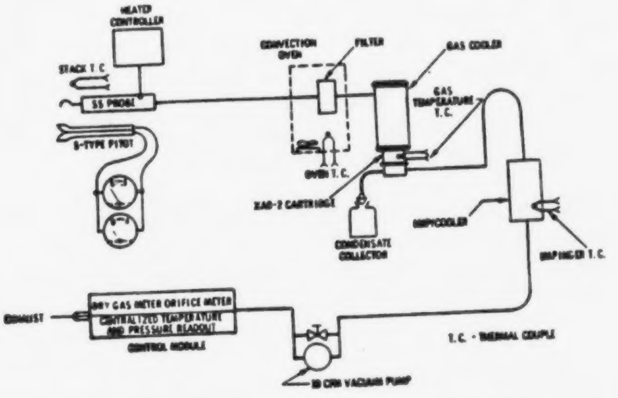
HEATER CONTROLLER
STACK T.C.
SS PROBE
S-TYPE PITOT
CONVECTION OVEN
FILTER
GAS COOLER
GAS TEMPERATURE T.C.
OVEN T.C.
XAD-2 CARTRIDGE
CONDENSATE COLLECTOR
IMP/COOLER
IMPINGER T.C.
EXHAUST
DRY GAS METER ORIFICE METER
CENTRALIZED TEMPERATURE AND PRESSURE READOUT
CONTROL MODULE
T.C. - THERMAL COUPLE
10 CFM VACUUM PUMP

Figure A-1. Schematic of Source Assessment Sampling System with program modifications.

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[50] Hamersma, J. W., S. L. Reynolds, and R. F. Maddalene. IERL-RTP Procedures Manual: Level I Environmental Assessment. EPA-600/2-76-160a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1976. 147 pp.

Prior to operating the SASS train, a velocity traverse and moisture determination were done at each sampling point using EPA Methods II [51] and IV [52]. The Fyrite method was used to determine the carbon dioxide and molecular oxygen content of the effluent stream. These tests were used to determine the point of average velocity and to characterize the source sufficiently for operating the sampling system as close to isokinetic conditions as possible within the available nozzle sizes and operating parameters. The sampling train was then assembled and leak checked. These procedures foolowed those outlined in the procedures manual [50] with the exceptions mentioned above. The first impinger was left empty, and the third impinger was charged with 750 g of silica gel. Once assembled, a leakage rate of $<2.36 \times 10^{-5}$ m^3 at 67.6 kPa was considered acceptable.

After passing the leak check, the probe and oven were heated to stack temperatures while maintaining the organic module at $\sim$20°C. Once the desired temperatures were obtained, the probe was inserted into the stack to a point of average velocity and sampling was initiated. Sampling was conducted at a rate of 1×10^{-3} m^3/s until a volume of approximately 14 m^3 (500 ft^3) was collected. At the conclusion of each run, the pumps were shut down, the probe was withdrawn from the stack, and the train was allowed to cool.

The cleanup procedures used are illustrated in Figure A-2. In brief, the filter was carefully removed from its holder and placed in a petri dish. The petri dish was then sealed with tape and labeled. A one-to-one methylene chloride:methanol mixture and a nylon brush were used to clean the probe tip, probe, and the front half of the filter holder. The methylene chloride:methanol used in the cleaning process was collected in the amber glass bottle. The back half of the filter holder and the line connecting it to the organic module were cleaned and the rinses bottled as described above.

The XAD-2 resin and aqueous condensate were removed from the organic module and separately bottled. The organic module was then cleaned as described in the procedures manual [50]. The methylene chloride:methanol used in the cleaning was combined with the rinse of the back half of the filter holder and connecting line.

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[51] Method 2 - Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube). Federal Register, 41(111):23063-23069, 1976.

[52] Method 4 - Determination of Moisture in Stack Gases. Federal Register, 41(111):23072-23076, 1976.

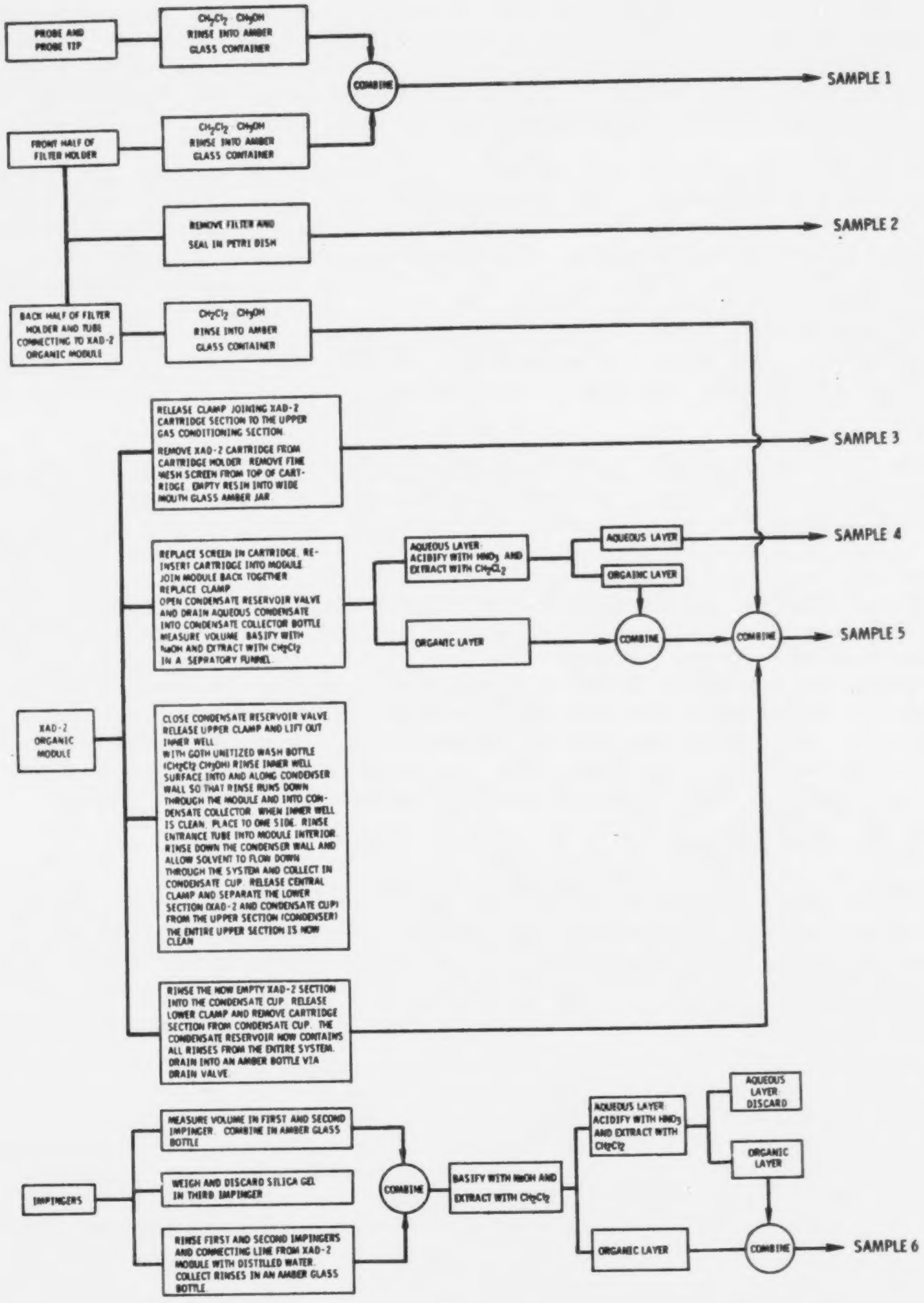

PROBE AND PROBE TIP
CH_2Cl_2 CH_3OH RINSE INTO AMBER GLASS CONTAINER
COMBINE
SAMPLE 1
FRONT HALF OF FILTER HOLDER
CH_2Cl_2 CH_3OH RINSE INTO AMBER GLASS CONTAINER
REMOVE FILTER AND SEAL IN PETRI DISH
SAMPLE 2
BACK HALF OF FILTER HOLDER AND TUBE CONNECTING TO XAD-2 ORGANIC MODULE
CH_2Cl_2 CH_3OH RINSE INTO AMBER GLASS CONTAINER
RELEASE CLAMP JOINING XAD-2 CARTRIDGE SECTION TO THE UPPER GAS CONDITIONING SECTION.
REMOVE XAD-2 CARTRIDGE FROM CARTRIDGE HOLDER. REMOVE FINE MESH SCREEN FROM TOP OF CARTRIDGE. EMPTY RESIN INTO WIDE MOUTH GLASS AMBER JAR.
SAMPLE 3
REPLACE SCREEN IN CARTRIDGE, REINSERT CARTRIDGE INTO MODULE. JOIN MODULE BACK TOGETHER. REPLACE CLAMP. OPEN CONDENSATE RESERVOIR VALVE AND DRAIN AQUEOUS CONDENSATE INTO CONDENSATE COLLECTOR BOTTLE. MEASURE VOLUME. BASIFY WITH NaOH AND EXTRACT WITH CH_2Cl_2 IN A SEPRATORY FUNNEL.
AQUEOUS LAYER: ACIDIFY WITH HNO_3 AND EXTRACT WITH CH_2Cl_2
AQUEOUS LAYER
SAMPLE 4
ORGAINIC LAYER
ORGANIC LAYER
COMBINE
COMBINE
SAMPLE 5
XAD-2 ORGANIC MODULE
CLOSE CONDENSATE RESERVOIR VALVE. RELEASE UPPER CLAMP AND LIFT OUT INNER WELL. WITH GOTH UNITIZED WASH BOTTLE (CH_2Cl_2 CH_3OH) RINSE INNER WELL SURFACE INTO AND ALONG CONDENSER WALL SO THAT RINSE RUNS DOWN THROUGH THE MODULE AND INTO CONDENSATE COLLECTOR. WHEN INNER WELL IS CLEAN, PLACE TO ONE SIDE. RINSE ENTRANCE TUBE INTO MODULE INTERIOR. RINSE DOWN THE CONDENSER WALL AND ALLOW SOLVENT TO FLOW DOWN THROUGH THE SYSTEM AND COLLECT IN CONDENSATE CUP. RELEASE CENTRAL CLAMP AND SEPARATE THE LOWER SECTION (XAD-2 AND CONDENSATE CUP) FROM THE UPPER SECTION (CONDENSER). THE ENTIRE UPPER SECTION IS NOW CLEAN
RINSE THE NOW EMPTY XAD-2 SECTION INTO THE CONDENSATE CUP. RELEASE LOWER CLAMP AND REMOVE CARTRIDGE SECTION FROM CONDENSATE CUP. THE CONDENSATE RESERVOIR NOW CONTAINS ALL RINSES FROM THE ENTIRE SYSTEM. DRAIN INTO AN AMBER BOTTLE VIA DRAIN VALVE.
IMPINGERS
MEASURE VOLUME IN FIRST AND SECOND IMPINGER. COMBINE IN AMBER GLASS BOTTLE
WEIGH AND DISCARD SILICA GEL IN THIRD IMPINGER
RINSE FIRST AND SECOND IMPINGERS AND CONNECTING LINE FROM XAD-2 MODULE WITH DISTILLED WATER. COLLECT RINSES IN AN AMBER GLASS BOTTLE.
COMBINE
BASIFY WITH NaOH AND EXTRACT WITH CH_2Cl_2
AQUEOUS LAYER: ACIDIFY WITH HNO_3 AND EXTRACT WITH CH_2Cl_2
AQUEOUS LAYER: DISCARD
ORGANIC LAYER
ORGANIC LAYER
COMBINE
SAMPLE 6

Figure A-2. Cleanup procedure for modified SASS train used in woven fabric finishing sampling.

Reproduced from best available copy.

The volume of the condensate collected in impingers one and two was measured and then bottled along with distilled water rinses of the impingers and the line connecting the organic module to the impingers. The silica gel was removed from the third impinger and weighed to determine its weight gain.

The aqueous condensate collected in the organic module was taken to the field laboratory and extracted. The condensate was first basified with sodium hydroxide (NaOH) and extracted three times with equal portions of methylene chloride. Next, the aqueous layer was acidified with nitric acid (HNO_3) and again extracted three times with methylene chloride. The organic layers from all six extractions were combined and bottled. The remaining aqueous layer was bottled separately. All of the liquid samples were iced down from transport to the analytical laboratory in Dayton.

The gas chromatographic work was done with an Analytical Instrument Development, Inc. (AID) model 511 portable gas chromatograph equipped with a flame ionization detector (FID), a gas sampling valve (GSV) and a column by-pass valve. This instrument was calibrated daily with standard methane mixtures in the 10, 100, 1,000, and 10,000 ppm ranges. Emission samples were drawn into the GSV by an electric pump attached to the GSV outlet via a stainless steel probe attached to the GSV inlet. At each location, samples were run straight through the FID (by passing the column) to determine the total hydrocarbon concentration and through a 6 ft stainless steel Chromosorb 102 column to determine the concentration of methane and the number of C_1 through C_6 compounds present. The results were recorded on a strip chart.

ANALYTICAL PROCEDURES

The samples collected in each SASS run are shown in Table A-1. The sample numbering system is the same as used in Figure A-2. Figure A-3 provides a summary of the sample workup and the analytical procedures which are described in detail in the following paragraphs.

Upon reaching the analytical laboratory, all liquid samples were logged in and then refrigerated until needed for analysis. The impinger solutions and the distilled water rinses of the first and second impingers were extracted. The combined solution was basified with sodium hydroxide and extracted with methylene chloride three times. The aqueous layer was then acidified with nitric acid (HNO_3) and again extracted three times with methylene chloride.

TABLE A-1. SAMPLES IDENTIFIED IN FIGURE A-2.

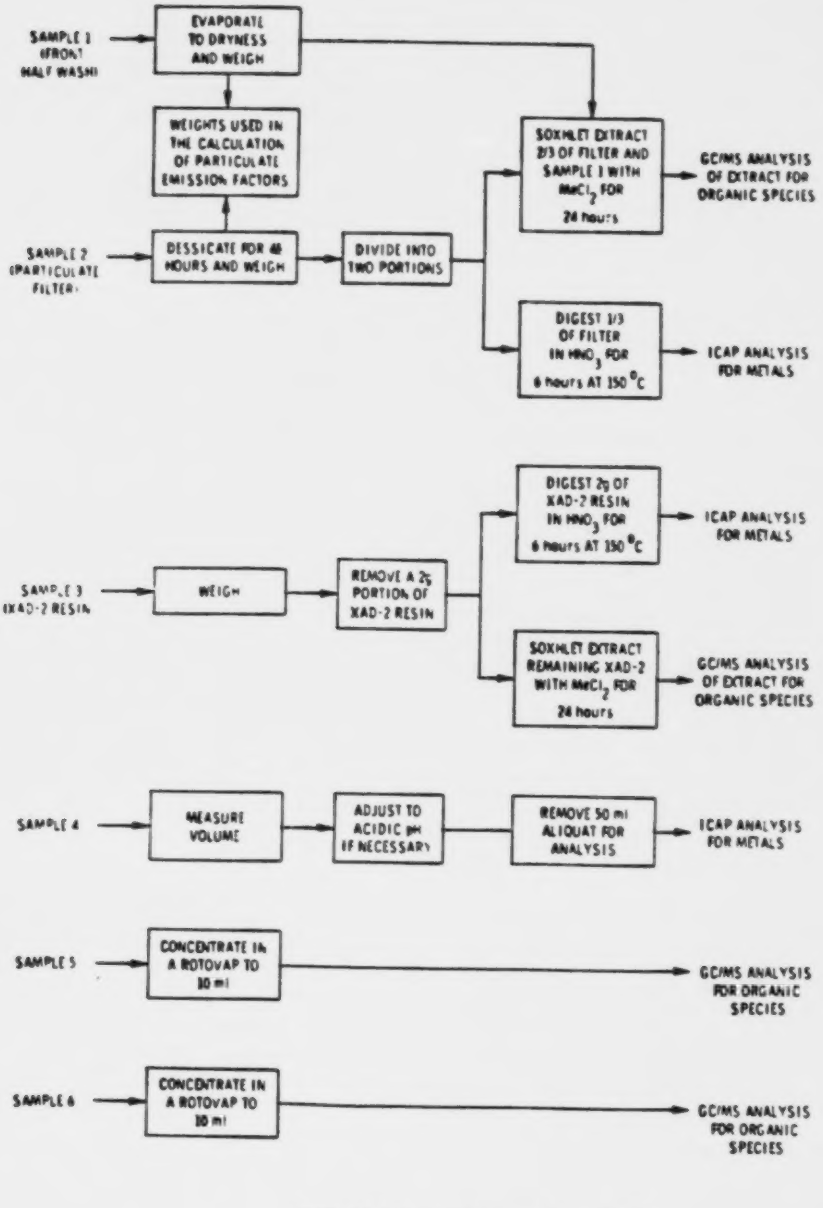
Sample number	Sample description	Sample analysis
Sample 1	CH_2Cl_2:CH_3OH rinse of probe, probe tip, and front half of filter holder.	Evaporate to dryness and weight for contribution to particulate catch: Add to portion of filter for organic extraction and GC/MS analysis.
Sample 2	Particulate filter.	Dessicate and weigh for particulate data; divide into two portions for organic (GC/MS) and trace element (ICAP) analysis.
Sample 3	XAD-2 resin.	2 g portion for trace metal (ICAP) analysis; remainder for organic extraction and GC/MS analysis.
Sample 4	Aqueous layer of organic module condensate.	Trace metal (ICAP) analysis.
Sample 5	CH_2Cl_2:CH_3OH rinse of back half of filter holder and filter to organic module connecting line, CH_2Cl_2 rinse of organic module, and CH_2Cl_2 layer of condensate extractions.	Organic (GC/MS) analysis.
Sample 6	CH_2Cl_2 layer of the impinger extracts.	Organic (GC/MS) analysis.

PARTICULATE SAMPLES

The combined probe tip, probe, and front half of the filter holder washes were evaporated to a low volume and transferred to a tared weighing pan. The solution was then evaporated to dryness and weighed. Particulate filters were dessicated for 48 hours and then weighed. Each filter was then divided into two sections and each was weighed. Approximately two-thirds (2/3) of the total weight of each filter was prepare for trace organic analysis and the remaining one-third (1/3) was prepared for trace element analysis.

TRACE ORGANIC ANALYSES

Four samples from each SASS run were analyzed for organic compounds. These consist of: the probe wash residue and two-thirds of the particulate filter catch; the XAD resin; the methylene chloride used to extract the organic module condensate combined with the methylene chloride:methanol rinses of the back half of


SAMPLE 1 (FRONT HALF WASH)
EVAPORATE TO DRYNESS AND WEIGH
WEIGHTS USED IN THE CALCULATION OF PARTICULATE EMISSION FACTORS
SAMPLE 2 (PARTICULATE FILTER)
DESSICATE FOR 48 HOURS AND WEIGH
DIVIDE INTO TWO PORTIONS
SOXHLET EXTRACT 2/3 OF FILTER AND SAMPLE 1 WITH MeCl$_2$ FOR 24 hours
GC/MS ANALYSIS OF EXTRACT FOR ORGANIC SPECIES
DIGEST 1/3 OF FILTER IN HNO$_3$ FOR 6 hours AT 150 °C
ICAP ANALYSIS FOR METALS
SAMPLE 3 (XAD-2 RESIN
WEIGH
REMOVE A 2g PORTION OF XAD-2 RESIN
DIGEST 2g OF XAD-2 RESIN IN HNO$_3$ FOR 6 hours AT 150 °C
ICAP ANALYSIS FOR METALS
SOXHLET EXTRACT REMAINING XAD-2 WITH MeCl$_2$ FOR 24 hours
GC/MS ANALYSIS OF EXTRACT FOR ORGANIC SPECIES
SAMPLE 4
MEASURE VOLUME
ADJUST TO ACIDIC pH IF NECESSARY
REMOVE 50 ml ALIQUAT FOR ANALYSIS
ICAP ANALYSIS FOR METALS
SAMPLE 5
CONCENTRATE IN A ROTOVAP TO 10 ml
GC/MS ANALYSIS FOR ORGANIC SPECIES
SAMPLE 6
CONCENTRATE IN A ROTOVAP TO 10 ml
GC/MS ANALYSIS FOR ORGANIC SPECIES

GC/MS-GAS CHROMATOGRAPHY/MASS SPECTROSCOPY
ICAP-INDUCTIVELY COUPLED ARGON PLASMA

Figure A-3. SASS sample analysis scheme.

the filter holder, the filter to organic module connecting line, and the organic module; and the methylene chloride used to extract the impinger solutions and rinses.

The probe wash residue and two-thirds of the filter were combined and Soxhlet extracted for 24 hours. The extract was then reduced in volume to below 10 mL in a roto-vap at 40°C under a vacuum of 30 mm Hg to 40 mm Hg. Approximately 2 g of each XAD-2 resin sample was removed for trace element analysis. The remainder of the XAD-2 resin was then Soxhlet extracted and concentrated as described above for the particulate catch. A blank batch of XAD-2 resin was prepared in the same manner. The two liquid samples were reduced in volume to <10 mL on the roto-vap apparatus. All four of the solutions from each run and the blank were then brought up to a volume of 10 mL with methylene chloride and submitted for GC/MS analysis.

The method used for organic analysis employs a peak-area quantitation technique with computer reconstructed chromatograms from a HP 5982-A GC/MS. All data was collected in the electron impact (EI) mode. The separation of the organics was accomplished with a 6 mm by 1.83 m glass column packed with 3% Dexsil 400 on Chromosorb W-MP. The column was temperature programmed at 80°C for 2 min followed by a 16°C per min increase to 280°C and isothermal operation at 280°C for 15 min. A carrier gas (helium) flow of 35 mL/min was used.

TRACE ELEMENT ANALYSES

Three samples from each SASS run were submitted for the analysis of trace metals. These were two solid samples consisting of one-third of the filter catch and a 2 g portion of the XAD-2 resin and one liquid sample consisting of an aliquot of the aqueous condensate collected in the organic module.

The filter samples, XAD-2 resin samples, a filter blank and a XAD-2 resin blank were prepared for trace element analysis by digestion in a 125 mL Parr acid digestion bomb. Each sample was loaded into a bomb along with 15 mL of concentrated redistilled nitric acid. The bomb was sealed and placed in an oven for 6 hours at 150°C. After cooling, the digest was removed by washing with hot distilled-deionized water. The insoluble remains of the glass fiber particulate filters were removed from the particulate matter samples by filtering. The residue remaining on the filter was washed with hot distilled-deionized water which was combined with the digest. The digest was then diluted to 250 mL with distilled-deionized water and a 50 mL aliquot was removed from each sample for trace element analysis. A 50 mL aliquot of the aqueous layer of the organic module condensate from each run was also removed for trace element analysis.

The 50 mL samples were submitted to the Physical Science Center of Monsanto Company in St. Louis for analysis by the Jarrel-Ash Plasma Atomcomp technique. The Atomcomp employs an inductively coupled argon plasma (ICAP) as an excitation source to produce an atomic emission which is relatively free of interferences. This system permits the simultaneous multielement determination of trace metals at the sub-ppm level in solutions.

APPENDIX B

EMISSIONS DATA OBTAINED FROM MRC SAMPLING PROGRAM

Results of the air emission measurements are presented in the following tables. The results in each table consist of a concentration of the specified pollutant in the effluent gas stream and an emission factor. Concentrations are given in milligrams (mg) of pollutant per actual cubic meter (m^3) or as ppm of the gas volume as measured in the stack. Emission factors relate the quantity of emissions to the quantity of product produced and the units are milligrams (mg) of pollutant per kilogram (kg) of fabric treated.

PLANT A DATA

TABLE B-1. PARTICULATE EMISSION FACTORS FOR PLANT A

Run No.	Operation sampled	Concentration of particulate in effluent gas steam mg/m^3 (actual)	Emission factor mg/kg of fabric
1	Finishing on No. 2 resin tenter frame (3rd zone	54	507
2	Dyeing on No. 4 Thermosol oven	68	144
3	No. 2 heat set (1st zone)	27	222

TABLE B-2. PLANT A, EMISSION DATA FOR ORGANIC COMPOUNDS - RUN 1: FINISHING ON NO. 2 RESIN TENTER FRAME (THIRD ZONE)

Organic species	Concentration in the effluent gas stream, mg/m³	Percentage found in the particulate phase, weight percent	Emission rate, kg/day	Emission factor, mg/kg of fabric
Diethyl phthalate	0.014	0	0.0037	0.13
Dipropyl phthalate	0.00022	0	0.000058	0.0021
Dibutyl phthalate	0.12	0	0.031	1.1
Di-C_8-alkyl phthalate	0.031	52	0.0083	0.29
Methyl palmitate	0.12	3	0.032	1.1
Methyl stearate	0.21	1	0.056	2.0
Methyl-C_{17}-ester	0.022	0	0.0058	0.21
Paraffins/olefins (C_{12}-C_{20})	0.065	0	0.017	0.61
Paraffins (C_{18}-C_{34})	11	10	2.8	100

TABLE 3-3. PLANT A, EMISSION DATA FOR ORGANIC COMPOUNDS - RUN 2: DYEING ON NO. 4 THERMOSOL OVEN

Organic species	Concentration in the effluent gas stream, mg/m³	Percentage found in the particulate phase, weight percent	Emission rate, kg/day	Emission factor, mg/kg of fabric
Diethyl phthalate	0.014	0	0.0026	0.051
Dipropyl phthalate	0.014	0	0.0025	0.050
Dibutyl phthalate	0.013	0	0.0023	0.047
Di-C_8-alkyl phthalate	0.040	15	0.0073	0.15
Methyl palmitate	4.9	0.3	0.88	18
Methyl stearate	5.6	0.5	1.0	20
Palmitic acid	0.43	0	0.078	1.6
Bromodinitrobenzene	0.83	0	0.15	3.0
Dichloronitroaniline	0.17	0	0.030	0.60
Bromodinitroaniline	0.34	0	0.062	1.2
Methyl-C_{11}-ester	0.11	0	0.020	0.40
Methyl-C_{12}-ester	0.18	0	0.032	0.65
Methyl-C_{13}-ester	0.15	0	0.026	0.53
Methyl-C_{14}-ester	0.99	0	0.18	3.6
Methyl-C_{15}-ester	0.49	0	0.089	1.8
Methyl-C_{17}-ester	1.1	0	0.20	4.0
Methyl-C_{18}-ester	0.24	0	0.044	0.88
Methyl-C_{20}-ester	0.13	0	0.024	0.48
Paraffins/olefins (C_{12}-$_{10}$)	0.73	0	0.13	2.6
Paraffins (C_{18}-C_{34})	1.7	17	0.30	6.1

TABLE B-4. PLANT A, EMISSION DATA FOR ORGANIC COMPOUNDS - RUN 3: NO. 2 HEAT SET (FIRST ZONE)

Organic species	Concentration in the effluent gas stream, mg/m³	Percentage found in the particulate phase, weight percent	Emission rate, kg/day	Emission factor, mg/kg of fabric
Diethyl phthalate	0.014	0	0.0034	0.19
Dipropyl phthalate	0.018	60	0.0045	0.25
Dibutyl phthalate	0.023	22	0.0055	0.31
Di-C_8-alkyl phthalate	0.069	27	0.017	0.95
Methyl palmitate	0.27	0	0.066	3.7
Methyl stearate	0.68	0	0.17	9.4
Methyl-C_{14}-ester	0.00035	0	0.000087	0.0049
Methyl-C_{17}-ester	0.028	0	0.0069	0.39
Paraffins/olefins (C_{12}-C_{20})	0.057	0	0.014	0.78
Paraffins (C_{18}-C_{34})	7.8	24	1.9	110

TABLE B-5. PLANT A, TOTAL HYDROCARBON EMISSIONS DATA AND TOTAL HYDROCARBON EMISSION FACTORS

Stack number	Process sampled	Total hydrocarbon concentration, ppm as CH_4[a]			Average concentration of methane, ppm	Nonmethane total hydrocarbon emission factors, mg/kg of fabric
		Peak 1	Peak 2	Total		
111	Aztec heat set	37	65	72	33	-[b]
132	No. 1 heat set, first zone	15	54	69	5	310
133	No. 1 heat set, second zone	20	52	72	6	370
142	No. 2 heat set, first zone	14	125	139	8	460
143	No. 2 heat set second zone	15	59	74	8	150
313	No. 1 Thermosol oven	8	0	8	0	062
313	No. 1 Thermosol oven	6	16	22	7	150
343	No. 4 Thermosol oven	8	17	25	3	057
422	No. 2 resin tenter, first exhaust	<1	<1	<1	0	0
423	No. 2 resin tenter, second exhaust	52	95	147	7	890
424	No. 2 resin tenter, third exhaust	111	18	129	74	550
425	No. 2 resin tenter. curing oven	3	4	7	5	-[b]
432	No. 3 resin tenter, first exhaust	50	20	70	30	200
433	No. 3 resin tenter, second exhaust	91	29	120	41	097
434	No. 3 resin tenter, third exhaust	27	41	68	22	065
452	No. 5 resin tenter, first exhaust	5	10	15	8	038
453	No. 5 resin tenter, second exhaust	5	5	10	4	029

[a] Conversion factor for ppm $\frac{mL}{m^3}$ to g/m³ is $\frac{16\ g}{mole}\ \frac{mole}{22{,}400\ mL}$.

[b] Flow rates could not be accurately measured for these stacks.

TABLE B-6. PLANT A, C_1-C_6 HYDROCARBON EMISSION DATA

Stack number	Process sampled	Number of C_1-C_6 compounds detected[a]	RRT[b]	Average concentration, ppm as CH_4
111	Aztec heat set	1	1.47	27
132	No. 1 heat set, first zone	1	1.46	46
133	No. 1 heat set, second zone	1	1.63	62
142	No. 2 heat set, first zone	1	1.81	165
143	No. 2 heat set, second zone	1	1.41	29
313	No. 1 Thermosol oven	0		
343	No. 4 Thermosol oven	1	6.76	2,049
422	No. 2 resin tenter, first exhaust	0		
423	No. 2 resin tenter, second exhaust	2	3.67	15
424	No. 2 resin tenter, third exhaust	3	1.69 1.98 3.96	2 2 15
425	No. 2 resin tenter, curing oven	0		
432	No. 3 resin tenter, first exhaust	0		
433	No. 3 resin tenter, second exhaust	2	1.96 3.73	<1 4
434	No. 3 resin tenter, third exhaust	1	3.67	19
452	No. 5 resin tenter, first exhaust	0		
453	No. 5 resin tenter, second exhaust	0		

Note. Blanks indicate that no C_1-C_6 compounds other than methane were detected.

[a] Other than CH_4.

[b] Retention time relative to the retention time for methane.

TABLE B-7. PLANT A, TRACE ELEMENT EMISSION DATA - RUN 1: FINISHING ON NO. 2 TENTER FRAME (3RD ZONE)

Element	Concentration in the effluent gas stream, mg/m³	Emission rate, kg/day	Emission factor, mg/kg of fabric
Aluminum	0.047	0.013	0.44
Antimony	0.034	0.0089	0.32
Barium	0.00040	0.00010	0.0037
Beryllium	0	0	0
Boron	0.0018	0.00048	0.017
Cadmium	0.00023	0.000062	0.0022
Calcium	0.027	0.0072	0.26
Chromium	0.034	0.0089	0.31
Cobalt	0.00073	0.00019	0.0069
Copper	0.037	0.0099	0.35
Iron	0.18	0.047	1.7
Lead	0.0029	0.00076	0.027
Magnesium	0.0072	0.0019	0.067
Manganese	0.0077	0.0020	0.072
Molybdenum	0.021	0.0057	0.20
Nickel	0.016	0.0041	0.15
Phosphorus	0.012	0.0033	0.12
Silicon	0	0	0
Silver	0	0	0
Sodium	2.5	0.65	23
Strontium	0.00034	0.000089	0.0032
Tin	0.076	0.020	0.71
Titanium	0.000029	0.0000077	0.00027
Vanadium	0	0	0
Zinc	0.035	0.0093	0.33

TABLE B-8. PLANT A, TRACE ELEMENT EMISSION DATA - RUN 2: DYEING ON NO. 4 THERMOSOL OVEN

Element	Concentration in the effluent gas stream, mg/m³	Emission rate, kg/day	Emission factor, mg/kg of fabric
Aluminum	0.020	0.0035	0.071
Antimony	0.022	0.0039	0.078
Barium	0.00028	0.000050	0.0010
Beryllium	0	0	0
Boron	0.111	0.0019	0.038
Cadmium	0.000076	0.000014	0.00028
Calcium	0.086	0.015	0.31
Chromium	0.020	0.0037	0.073
Cobalt	0.00082	0.00015	0.0030
Copper	0.012	0.0022	0.044
Iron	0.068	0.012	0.25
Lead	0.0043	0.00078	0.016
Magnesium	0.016	0.0029	0.057
Manganese	0.0046	0.00083	0.017
Molybdenum	0.014	0.0025	0.050
Nickel	0.020	0.0035	0.071
Phosphorus	0.020	0.0035	0.070
Silicon	0	0	0
Silver	0.00042	0.000075	0.0015
Sodium	100	18	360
Strontium	0.00085	0.00015	0.0031
Tin	0.078	0.014	0.28
Titanium	0.00024	0.000044	0.00088
Vanadium	0.000042	0.0000075	0.00015
Zinc	0.021	0.0038	0.076

TABLE B-9. PLANT A, TRACE ELEMENT EMISSION DATA - RUN 3. NO. 2 HEAT SET (1ST ZONE)

Element	Concentration in the effluent gas stream, mg/m³	Emission rate, kg/day	Emission factor, mg/kg of fabric
Aluminum	0.0011	0.00019	0.015
Antimony	0.0031	0.00055	0.043
Barium	0.00020	0.000035	0.0027
Beryllium	0.00035	0.0000062	0.00049
Boron	0.00013	0.000024	0.0019
Cadmium	0.00025	0.000045	0.0035
Calcium	0.0049	0.00086	0.068
Chromium	0.00093	0.00016	0.013
Cobalt	0.00033	0.000059	0.0046
Copper	0.0011	0.00019	0.015
Iron	0.0051	0.00089	0.070
Lead	0.0021	0.00036	0.029
Magnesium	0.00086	0.00015	0.012
Manganese	0.00059	0.00010	0.0081
Molybdenum	0.013	0.0023	0.18
Nickel	0.0034	0.00060	0.047
Phosphorus	0.0052	0.00092	0.072
Silicon	0	0	0
Silver	0.0069	0.00012	0.0096
Sodium	28	5.0	390
Strontium	0.00018	0.000032	0.0026
Tin	0.044	0.0077	0.61
Titanium	0.000021	0.0000037	0.00030
Vanadium	0.00011	0.000020	0.0016
Zinc	0.0040	0.00071	0.056

TABLE B-10. ESTIMATION OF EMISSION FACTORS FROM SAMPLING DATA - HEAT SETTING AT PLANT A

Emission species	Emission factors measured for 1st zone,[a] mg/kg of fabric	Emission factors estimated for 2nd zone of heat set,[b] mg/kg of fabric	Emission factors estimated for total heat set (zones 1 and 2),[c] mg/kg of fabric
Particulate matter	222	72	294
Organic compounds			
Diethyl phthalate	0.19	0.062	0.25
Dipropyl phthalate	0.25	0.081	0.33
Dibutyl phthalate	0.31	0.10	0.41
Di-C_8-alkyl phthalate	0.95	0.31	1.3
Methyl palmitate	3.7	1.2	4.9
Methyl stearate	9.4	3.1	12
Methyl-C_{16}-ester	0.0049	0.0016	0.0065
Methyl-C_{17}-ester	0.39	0.13	0.52
Aliphatics (C_{12}-C_{34})	110	36	150
Nonmethane total hydrocarbons	460	150[d]	610[d]
Trace elements[e]			
Aluminum	0.015	0.0049	0.020
Antimony	0.043	0.014	0.057
Barium	0.0027	0.00088	0.0036
Beryllium	0.00049	0.00016	0.00065
Boron	0.0019	0.00062	0.0025
Cadmium	0.0035	0.0011	0.0046
Calcium	0.068	0.022	0.090
Chromium	0.013	0.0042	0.017
Cobalt	0.0046	0.0015	0.0061
Copper	0.015	0.0049	0.020
Iron	0.070	0.023	0.093
Lead	0.029	0.0095	0.038
Magnesium	0.012	0.0039	0.016
Manganese	0.0081	0.0026	0.011
Molybdenum	0.18	0.059	0.24
Nickel	0.047	0.015	0.062
Phosphorus	0.072	0.023	0.095
Silver	0.0096	0.0031	0.013
Sodium	390	127	520
Strontium	0.0026	0.00085	0.0034
Tin	0.61	0.20	0.81
Titanium	0.00030	0.000098	0.00040
Vanadium	0.0016	0.00052	0.0021
Zinc	0.056	0.018	0.074

[a] The heat setting equipment sampled had 2 exhaust stacks only one of which was sampled for trace organics and trace elements. Each stack exhausts a section of the machine designated as zones 1 and 2.

[b] Emission factors for the second zone were estimated by using the ratio of the total nonmethane hydrocarbon emission factor for zone 1 to that of zone 2 as a multiplier for the various emission factors determined for zone 1.

[c] Estimated by adding the values measured for zone 1 to the values estimated for zone 2.

[d] This value was measured rather than estimated.

[e] These samples were also analyzed for silicon which was not detected.

TABLE B-11. ESTIMATION OF EMISSION FACTORS FROM SAMPLING DATA - FINISHING TENTER FRAME AT PLANT A

Emission species	Emission factors estimated for 1st zone of tenter frame,[a] mg/kg of fabric	Emission factors estimated for 2nd zone of tenter frame,[b] mg/kg of fabric	Emission factors measured for 3rd zone of tenter frame,[c] mg/kg of fabric	Emission factors estimated for total tenter frame,[d] (zones 1, 2, and 3) mg/kg of fabric
Particulate matter	0	820	507	1,300
Organic compounds				
Diethyl phthalate	0	0.21	0.13	0.34
Dipropyl phthalate	0	0.0034	0.0021	0.0055
Dibutyl phthalate	0	1.8	1.1	2.9
Di-C_8-alkyl phthalate	0	0.45	0.29	0.76
Methyl palmitate	0	1.8	1.1	2.9
Methyl stearate	0	3.2	2.0	5.2
Methyl-C_{17}-esters	0	0.34	0.21	0.55
Aliphatics (C_{12}-C_{34})	0	160	101	260
Nonmethane total hydrocarbons	0	890[e]	550	1,400[e]
Trace elements[f]				
Aluminum	0	0.71	0.44	1.2
Antimony	0	0.52	0.32	0.84
Barium	0	0.0060	0.0037	0.0097
Boron	0	0.028	0.017	0.045
Cadmium	0	0.0036	0.0022	0.0058
Calcium	0	0.42	0.26	0.68
Chromium	0	0.50	0.31	0.81
Cobalt	0	0.011	0.0069	0.018
Copper	0	0.57	0.35	0.92
Iron	0	2.8	1.7	4.5
Lead	0	0.044	0.027	0.071
Magnesium	0	0.11	0.067	0.18
Manganese	0	0.12	0.072	0.19
Molybdenum	0	0.32	0.20	0.52
Nickel	0	0.24	0.15	0.39
Phosphorus	0	0.19	0.12	0.31
Sodium	0	37	23	60
Strontium	0	0.0052	0.0032	0.0084
Tin	0	1.1	0.71	1.8
Titanium	0	0.00044	0.00027	0.00071
Zinc	0	0.53	0.33	0.86

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[a] This exhaust stack had no flow; it is assumed that the emissions from zone 1 were exhausted through the zone 2 stack.

[b] Estimated by multiplying the emission factors measured for the 3rd zone by the ratio of the nonmethane total hydrocarbon emission factor for zone 2 to that for zone 3.

[c] Measured by stack testing.

[d] Total of emission factors estimated for zones 1 and 2 and those measured for zone 3.

[e] These values were measured rather than estimated.

[f] Elements not detected during analysis are beryllium, silicon, silver, and vanadium.

TABLE B-12. PLANT B, CHARACTERISTICS OF THE EFFLUENT GAS STREAMS SAMPLED WITH THE SASS TRAIN

Effluent parameter	Units	Run 1: Dyeing on a thermosol dye range	Run 2: Curing of a finish in a curing oven	Run 3: Finishing/drying on a finishing tenter frame
Oxygen (O_2) content	Volume %	-[a]	-[a]	20.5
Carbon dioxide (CO_2) content	Volume %	-[a]	-[a]	2.0
Nitrogen (N_2) content	Volume %	-[a]	-[a]	77.5
Moisture (H_2O) content	Volume %	4.24	3.50	3.53
Dry molecular weight of stack gas	g/mole	29.14[b]	29.14[b]	29.14
Molecular weight of stack gas	g/mole	28.67[c]	28.75[c]	28.75
Stack gas temperature (average)	°C	192	145	151
Stack gas temperature (range)	°C	185 to 197	139 to 152	137 to 167
Average stack gas velocity	m/s	9.58	9.16	5.51
Average stack gas flow rate (actual)	m^3/s	3.035	2.553	1.744
Average stack gas flow rate (standard conditions)	m^3/s	1.862	1.754	1.180

[a] Not measured.

[b] Assumed to be the same as for Run 3.

[c] Based on the assumed dry molecular weight of 29.14 g/mole.

TABLE B-13. PLANT B, PARTICULATE EMISSION FACTORS

Run No.	Operation sampled	Concentration of particulate in effluent gas stream, mg/m^3[a]	Particulate contribution to the total emissions weight %	Emission rate[b] kg/day	Emission factor mg/kg of fabric
1	Dyeing on Thermosol dye range	59	0.0075	15.5	410
2	Curing of a finish on curing oven No. 1	32	0.0037	7.1	340
3	Finishing/drying on Krantz finishing frame No. 1 - zone 1	39	0.0045	5.9	440

[a] Actual cubic meters.

[b] Based on continuous operation for a 24-hour day.

TABLE B-14. PLANT B, EMISSION DATA FOR ORGANIC COMPOUNDS - RUN 1: DYEING ON THERMOSOL DYE RANGE

Organic species	Concentration in the effluent gas stream, mg/m³	Percentage of compound collected in the particulate phase weight %	Emission rate kg/day	Emission factor mg/kg of fabric
C_4+C_5 alkyl benzenes	0.25	0	0.066	1.7
Dichlorobenzenes	0.23	0	0.060	1.6
Trichlorobenzenes	0.099	0	0.026	0.68
Napthalene	0.24	0	0.062	1.6
Methyl-napthalenes	0.93	0	0.24	6.4
Dimethyl-napthalenes	0.54	0	0.14	3.7
C_3 and above napthalenes	0.0023	0	0.00062	0.016
Butyl benzoate	1.5	0	0.40	10.7
Biphenyl	0.94	0	0.25	6.5
Dimethyl phthalate	0.21	0	0.054	1.4
Diethyl phthalate	0.00035	100	0.00009	0.0024
Di-C_8 alkyl-phthalate	0.0030	93	0.00080	0.021
Bromochlorobenzene	0.018	0	0.0048	0.13
Bromodinitrobenzene	0.93	0	0.24	6.4
Anthraquinone	2.8	0	0.74	19.0
Aminoanthraquinone	0.36	0	0.093	2.5
Methyl myristate	0.014	0	0.0036	0.094
Methyl palmitate	1.1	0.07	0.30	7.8
Methyl stearate	2.5	0.02	0.66	17.5
Aliphatics	6.5	2	1.7	44.8

TABLE B-15. PLANT B, EMISSION DATA FOR ORGANIC COMPOUNDS - RUN 2: CURING OF A FINISH ON CURING OVEN NO. 1

Organic species	Concentration in the effluent gas stream, mg/m³	Percentage of compound collected in the particulate phase weight %	Emission rate kg/day	Emission factor mg/kg of fabric
C_4+C_5 alkyl benzenes	0.11	0	0.024	1.1
Trichlorobenzenes	0.0061	0	0.0013	0.064
Napthalene	0.059	0	0.013	0.63
Methyl-napthalenes	0.20	0	0.045	2.1
Dimethyl-napthalenes	0.089	0	0.020	0.94
C_3 and above napthalenes	0.034	0	0.0074	0.35
Butyl benzoate	0.47	0	0.10	4.9
Biphenyl	0.26	0	0.057	2.7
Dimethyl phthalate	0.091	0	0.020	0.97
Diethyl phthalate	0.00021	0	0.00005	0.0022
Dipropyl phthalate	0.0011	88	0.00025	0.012
Dibutyl phthalate	0.0050	100	0.0011	0.053
Di-C_8 alkyl phthalate	0.0012	100	0.00026	0.013
Dimethyl alkyl amines	4.3	0.4	0.96	45.9
Bromodinitrobenzene	0.030	0	0.0067	0.32
Dichloronitroaniline	0.012	0	0.0026	0.13
Anthraquinone	0.0065	0	0.0014	0.069
Methyl dodecanoate	0.00099	0	0.00022	0.010
Methyl myristate	0.0037	0	0.00081	0.039
Methyl palmitate	0.0072	0	0.0016	0.076
Methyl stearate	0.0074	0	0.0016	0.078
Aliphatics	12.7	2	2.8	134

TABLE B-16. PLANT B, EMISSION DATA FOR ORGANIC COMPOUNDS - RUN 3: FINISHING AND DRYING ON KRANTZ FINISHING FEAME NO. 1 - ZONE 1

Organic species	Concentration in the effluent gas stream, mg/m³	Percentage of compound collected in the particulate phase weight %	Emission rate kg/day	Emission factor mg/kg of fabric
Dichlorobenzenes	0.72	0	0.11	8.1
Trichlorobenzenes	17	0	2.6	192
Tetrachlorobenzenes	0.77	0	0.12	8.6
Methyl-napthalenes	1.2	0	0.17	12.8
Dimethyl-napthalenes	1.4	0	0.21	15.8
C_3 and above napthalenes	0.48	0	0.072	5.3
Butyl benzoate	21	0	3.1	230
Biphenyl	11	0	1.7	125
Dimethyl phthalate	17	0	2.6	195
Di-C_8-alkyl phthalate	0.0016	100	0.00024	0.018
Bromodinitrobenzene	1.8	0	0.27	20.1
Anthraquinone	0.20	0	0.031	2.3
Aminoanthraquinone	0.020	0	0.0030	0.22
Methyl dodecanoate	0.15	0	0.023	1.7
Methyl myristate	0.069	0	0.010	0.76
Methyl palmitate	0.18	0	0.028	2.1
Methyl stearate	0.079	0	0.012	0.88
Aliphatics	12	1	1.8	131

TABLE B-17. PLANT B, CHARACTERISTICS OF EFFLUENT GAS STREAMS ANALYZED BY GAS CHROMATOGRAPHY

GC run numbers	Stack identification	Moisture content volume %	Stack gas temperature °C	Stack gas velocity m/s	Stack gas flow rate m^3/s[a]
1,10	Clip frame - stack 1 (zone 1)	5.15	111	7.76	2.072
2,9	Clip frame - stack 2 (zone 2)	6.91	168	7.89	1.374
3	Pin frame - stack 1 (zone 1)	7.45	160	12.24	3.269
4	Pin frame - stack 2 (zone 2)	3.08	138	6.29	1.173
17	Krantz frame No. 1 - stack 1 (zone 1)	3.53	151	5.51	1.744
15,16	Krantz frame No. 1 - stack 2 (zone 2)	3.50	137	5.15	1.629
5	Thermosol dye range	4.24	192	9.58	3.035
7	Range No. 1 - stack 1 (zone 1)	7.27	125	14.40	5.370
8	Range No. 1 - stack 2 (zone 2)	4.74	120	2.34	0.872
6	Curing oven No. 1	3.50	145	9.16	2.553
13	Range No. 2 - stack 2 (zone 2)	1.98	139	13.85	2.681
14	Range No. 2 - stack 3 (zone 3)	-[b]	-[b]	-[b]	-[b]
12	Curing oven No. 2	-[b]	-[b]	-[b]	-[b]
11	Thermosol preparation line - 3rd steamer vent	-[b]	-[b]	-[b]	-[b]

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[a] Actual cubic meters per second.

[b] No measurements were made on these stacks.

TABLE B-18. PLANT B, NONMETHANE TOTAL HYDROCARBON EMISSION DATA

GC run numbers	Equipment sampled	Operation sampled	Average total hydrocarbon concentration ppm as CH_4[a]	Average methane concentration ppm as CH_4[a]	Nonmethane total hydrocarbon concentration mg/m³ as CH_4	Nonmethane total hydrocarbon emission rate kg/day	Nonmethane total hydrocarbon emission factor g/kg of fabric
1	Clip frame - 1st zone	Finishing	7,610	4,557	2,180	388	14.4
2	Clip frame - 2nd zone	Finishing	2,260	2,023	169	20	0.74
3	Pin frame - 1st zone	Drying	1,010	631	271	77	5.6
4	Pin frame - 2nd zone	Drying	466	324	101	10	0.75
5	Thermosol dye range	Dyeing	602	461	101	26	1.3
6	Curing oven No. 1	Curing	3,830	2,714	797	176	9.3
7	Range No. 1 (finishing and heat set) 2nd zone	Finishing	804	307	355	27	1.4
8	Range No. 1 (finishing and heat set) 1st zone	Finishing	821	682	99	46	2.4
9	Clip frame - 2nd zone	Drying	1,975	1,572	284	34	1.4
10	Clip frame - 1st zone	Drying	5,110	1,946	2,260	405	16.3
11	Thermosol preparation line 3rd steamer vent	Preparation for dyeing	20	4	11	-[b]	-[b]
12	Curing oven No. 2	Curing	3,640	2,913	519	-[b]	-[b]
13	Range No. 2 (finishing and heat set) 2nd zone	Finishing	44	24	14	3	0.17
14	Range No. 2 (finishing and heat set) 3rd zone	Finishing	61	35	19	-[b]	-[b]
15	Krantz finishing frame No. 1 2nd zone	Finishing	120	133	0	0	0
16	Krantz finishing frame No. 1 2nd zone	Finishing	309	89	157	22	1.7
17	Krantz finishing frame No. 1 1st zone	Finishing	374	350	17	3	0.19

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[a] The conversion factor for ppm $\left(\frac{\text{mL}}{\text{m}^3}\right)$ as CH_4 to mg/m³ as CH_4 is $\left(\frac{\text{lb g}}{\text{mole}}\right)\left(\frac{\text{mole}}{22{,}400\ \text{mL}}\right)\left(\frac{1{,}000\ \text{mg}}{\text{g}}\right)$.

[b] Flow rates were not determined for these stacks. Therefore, the emission rates and emission factors cannot be calculated, however, the concentration data is provided for comparison purposes.

TABLE B-19. PLANT B, TRACE ELEMENT EMISSION DATA - RUN 2: CURING OF A FINISH ON CURING OVEN NO. 1

Element	Concentration in the effluent gas stream, mg/m^3	Emission rate, kg/day	Emission factor, mg/kg of fabric
Aluminum	0	0	0
Antimony	0.0083	0.0018	0.088
Barium	0.00042	0.000092	0.0044
Beryllium	0.00041	0.000090	0.0043
Boron	0.00073	0.00016	0.0077
Cadmium	0	0	0
Calcium	0.11	0.024	1.1
Chromium	0.0012	0.00026	0.012
Cobalt	0.000014	0.0000031	0.00015
Copper	0.12	0.027	1.3
Iron	0.0068	0.0015	0.072
Lead	0.0021	0.00047	0.022
Magnesium	0.021	0.0045	0.22
Manganese	0.00022	0.000048	0.0023
Molybdenum	0.0064	0.0014	0.067
Nickel	0	0	0
Phosphorus	0.0069	0.0015	0.073
Silicon	0.0062	0.0014	0.066
Silver	0.037	0.0082	0.39
Sodium	14	3.1	150
Strontium	0.00029	0.000064	0.0031
Tin	0.035	0.0078	0.37
Titanium	0.00025	0.000054	0.0026
Vanadium	0	0	0
Zinc	0.086	0.019	0.91

TABLE B-20. PLANT B, TRACE ELEMENT EMISSION DATA - RUN 1: DYEING ON THERMOSOL DYE RANGE

Element	Concentration in the effluent gas stream, mg/m³	Emission rate, kg/day	Emission factor, mg/kg of fabric
Aluminum	0.027	0.0072	0.19
Antimony	0.0065	0.0017	0.045
Barium	0.0031	0.00082	0.022
Beryllium	0.000028	0.0000072	0.00019
Boron	0.0064	0.0017	0.044
Cadmium	0.00056	0.00015	0.0039
Calcium	0.12	0.031	0.81
Chromium	0.032	0.0084	0.22
Cobalt	0.00077	0.00020	0.0053
Copper	0.0043	0.0011	0.030
Iron	0.052	0.014	0.36
Lead	0.0060	0.0016	0.041
Magnesium	0.029	0.0075	0.20
Manganese	0.0036	0.00095	0.025
Molybdenum	0.0049	0.0013	0.034
Nickel	0.016	0.0043	0.11
Phosphorus	0.023	0.0059	0.16
Silicon	0.070	0.018	0.49
Silver	0.18	0.046	1.2
Sodium	56	15	380
Strontium	0.00041	0.00011	0.0028
Tin	0.010	0.0027	0.072
Titanium	0.00043	0.00011	0.0030
Vanadium	0.00088	0.00023	0.0061
Zinc	0.017	0.0045	0.12

TABLE B-21. PLANT B, TRACE ELEMENT EMISSION DATA - RUN 3: FINISHING AND DRYING ON KRANTZ FINISHING FRAME NO. 1 - ZONE 1

Element	Concentration in the effluent gas stream, mg/m³	Emission rate, kg/day	Emission factor, mg/kg of fabric
Aluminum	0.17	0.037	1.9
Antimony	0.019	0.0040	0.21
Barium	0.0020	0.00042	0.022
Beryllium	0.00043	0.000092	0.0048
Boron	0.0040	0.00085	0.045
Cadmium	0.0018	0.00038	0.020
Calcium	0.019	0.0040	0.21
Chromium	0.0032	0.00068	0.36
Cobalt	0.0030	0.00064	0.033
Copper	0.0056	0.0012	0.062
Iron	0.038	0.0079	0.42
Lead	0.020	0.0042	0.22
Magnesium	0.064	0.013	0.71
Manganese	0.00092	0.00019	0.010
Molybdenum	0.035	0.0073	0.38
Nickel	0.027	0.0058	0.30
Phosphorus	0.082	0.017	0.91
Silicon	0.68	0.14	7.5
Silver	0.025	0.0053	0.28
Sodium	49	10	540
Strontium	0.00033	0.000070	0.0037
Tin	0.018	0.0039	0.20
Titanium	0.0024	0.00050	0.026
Vanadium	0.011	0.0022	0.12
Zinc	0.019	0.0041	0.21

TABLE B-22. ESTIMATION OF EMISSION FACTORS FROM SAMPLING DATA - FINISHING/DRYING TENTER FRAME AT PLANT B

Emission species	Emission factors measured for 1st zone of tenter frame,[a] mg/kg of fabric	Emission factors estimated for 2nd zone of tenter frame,[b] mg/kg of fabric	Emission factors estimated for total tenter frame,[c] mg/kg of fabric
Particulate matter	440	440	880
Organic compounds			
Dichlorobenzenes	8.1	8.1	16
Trichlorobenzenes	192	192	380
Tetrachlorobenzenes	8.6	8.6	17
Methyl napthalenes	12.8	12.8	26
Dimethyl napthalenes	15.8	15.8	32
C_3 and above napthalenes	5.3	5.3	11
Butyl benzoate	230	230	460
Biphenyl	125	125	150
Dimethyl phthalate	195	195	390
Ci-C_8-alkyl phthalate	0.018	0.018	0.036
Bromodinitro benzene	20.1	20.1	40
Anthraquinone	2.3	2.3	4.6
Aminoanthraquinone	0.22	0.22	0.44
Methyl dodecanoate	1.7	1.7	3.4
Methyl myristate	0.76	0.76	1.5
Methyl palmitate	2.1	2.1	4.2
Methyl stearate	0.88	0.88	1.8
Aliphatics	131	131	260
Nonmethane total hydrocarbons	190	190	380
Trace elements			
Aluminum	1.9	1.9	3.8
Antimony	0.21	0.21	0.42
Barium	0.22	0.022	0.044
Beryllium	0.0048	0.0048	0.0096
Boron	0.045	0.045	0.090
Cadmium	0.020	0.020	0.040
Calcium	0.21	0.21	0.42
Chromium	0.36	0.36	0.72
Cobalt	0.033	0.033	0.066
Copper	0.062	0.062	0.12
Iron	0.42	0.42	0.84
Lead	0.22	0.22	0.44
Magnesium	0.71	0.71	1.4
Manganese	0.010	0.010	0.020
Molybdenum	0.38	0.38	0.76
Nickel	0.30	0.30	0.60
Phosphorus	0.91	0.91	1.8
Silicon	7.5	7.5	15
Silver	0.28	0.28	0.56
Sodium	540	540	1,080
Strontium	0.0037	0.0037	0.0074
Tin	0.20	0.20	0.40
Titanium	0.026	0.026	0.052
Vanadium	0.12	0.12	0.24
Zinc	0.21	0.21	0.42

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[a] The tenter frame sampled had 2 exhaust stacks only one of which was sampled for trace organics and elements. Each stack exhausts a section of the machine designated as zones 1 and 2.

[b] Due to conflicting results received from duplicate total nonmethane hydrocarbon emission measurements made on the 2nd zone of the tenter frame, emission factor estimates will be made by assuming that they are the same as measured for the 1st zone.

TABLE B-23. PLANT C, CHARACTERISTICS OF THE EFFLUENT GAS STREAMS SAMPLED WITH THE SASS TRAIN

Effluent parameter	Units	Run 1: 2nd zone of curing oven No. 4	Run 2: 3rd zone of finishing tenter frame No. 4	Run 3: 2nd zone of Thermosol oven No. 11
Moisture (H_2O) content	Volume %	3.83	4.85	2.54
Molecular weight of stack gas	g/mole	28.675[a]	28.562[a]	28.818[a]
Stack gas temperature (average)	°C	168	127	154
Stack gas temperature (range)	°C	157 to 175	111 to 142	152 to 158
Average stack gas velocity	m/s	6.58	11.08	6.89
Stack gas flow rate (actual)	m^3/s	2.14	3.09	3.39
Stack gas flow rate (standard conditions)	m^3/s	1.35	2.13	2.26

[a] Based on an assumed dry molecular weight of 29.10 (estimated from previous measurements of similar effluent streams).

TABLE B-24. PLANT C, PARTICULATE EMISSION DATA

Run No.	Operation sampled	Concentration of particulate in effluent gas stream, mg/m^3[a]	Particulate contribution to the total emissions weight %	Emission rate[b] kg/day	Emission factor mg/kg of fabric
1	Curing of a permanent press finish (2nd zone of curing oven No. 4)	2.6	0.0003	17	18
2	Application and drying of a permanent press finish (3rd zone of finishing tenter frame No. 4)	3.4	0.0004	32	34
3	Dyeing on a Thermosol dye range (2nd zone of Thermosol oven No. 11)	5.9	0.007	61	53

[a] Actual cubic meters.

[b] Based on continuous operation of a 24-hr day.

TABLE B-25. PLANT C, ORGANIC EMISSION DATA - SASS RUN 1: CURING OF A PERMANENT PRESS FINISH, 2ND ZONE OF CURING OVEN

Organic species	Concentration in the effluent gas stream mg/m³[a]	Percentage found in the particulate phase weight %	Emission rate[b] kg/day	Emission factor mg/kg of fabric
$C_3/C_4/C_5$-alkylbenzenes	0.067	0	0.43	0.46
Ethyl styrene	0.13	0	0.87	0.93
Divinyl benzene	0.014	0	0.090	0.097
Dichloro benzene	0.0014	0	0.0090	0.0096
Naphthalene	0.064	0	0.42	0.45
Methyl-naphthalenes	0.0057	0	0.037	0.040
Dimethyl-naphthalenes	0.011	0	0.072	0.077
Butyl benzoate	0.22	0	1.4	1.5
Biphenyl	0.11	0	0.70	0.75
Dimethyl phthalate	1.3	0	8.6	9.2
Dibutyl phthalate	0.039	0	0.26	0.27
Di-C_8-alkyl phthalate	0.0079	24	0.052	0.055
C_8-phenol	0.020	0	0.13	0.14
C_9-phenols	0.090	0	0.59	0.63
Bromodinitrobenzene	0.24	0	1.6	1.7
Anthraquinone	0.27	0	1.8	1.9
Methyl myristate	0.079	0	0.51	0.55
Methyl palmitate	1.5	0	10.0	10.7
Methyl stearate	2.0	0	13.1	14.0
Palmitic acid	0.92	0	6.0	6.4
Diphenyl ethane	0.066	0	0.43	0.46
Ethyl-phenyl-phenyl-ethane	0.095	0	0.62	0.66
Aliphatics	0.62	3	4.1	4.4

[a] Actual cubic meters.

[b] Based on continuous operation for a 24-hr period.

TABLE B-26. PLANT C, ORGANIC EMISSION DATA - SASS RUN 2: APPLICATION AND DRYING OF A PERMANENT PRESS FINISH, 3RD ZONE OF FINISHING TENTER FRAME

Organic species	Concentration in the effluent gas stream mg/m^3 [a]	Percentage found in the particulate phase weight %	Emission rate[b] kg/day	Emission factor mg/kg of fabric
$C_3/C_4/C_5$-alkylbenzenes	0.31	0	3.0	3.2
Ethyl styrene	0.51	0	4.8	5.2
Divinyl benzene	0.057	0	0.54	0.58
Naphthalene	0.15	0	1.4	1.5
Methyl-naphthalenes	0.0071	0	0.067	0.071
Dimethyl-naphthalenes	0.010	0	0.094	0.10
Butyl benzoate	0.010	0	0.10	0.11
Biphenyl	0.017	0	0.16	0.17
Dimethyl phthalate	0.40	0	3.8	4.1
Dibutyl phthalate	0.044	0	0.41	0.44
Di-C_8-alkyl phthalate	0.014	24	0.14	0.15
C_9-phenols	0.032	100	0.30	0.32
t-Butyl-hydroxyanisole	0.0023	100	0.021	0.023
Bromodinitrobenzene	0.087	0	0.82	0.88
Anthraquinone	0.12	0	1.2	1.2
Methyl myristate	0.057	2	0.53	0.57
Methyl palmitate	0.85	1	8.0	8.5
Methyl stearate	1.1	1	10.6	11.3
Diphenyl ethane	0.11	0	1.0	1.1
Ethyl-phenyl-phenyl-ethane	0.19	0	1.8	1.9
Octamethylcyclotetrasiloxane	0.20	0	1.9	2.1
Siloxane (dominant ion 267)	0.076	0	0.72	0.77
Siloxane (dominant ion 341)	0.036	0	0.34	0.37
Aliphatics	1.5	12	14.2	15.2

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[a] Actual cubic meters.

[b] Based on continuous operation of a 24-hr period.

TABLE B-27. PLANT C, ORGANIC EMISSION DATA - SASS RUN 3: DYEING ON A THERMOSOL DYE RANGE, 2ND ZONE OF THERMOSOL OVEN

Organic species	Concentration in the effluent gas stream mg/m³[a]	Percentage found in the particulate phase weight %	Emission rate[b] kg/day	Emission factor mg/kg of fabric
2-Ethylhexanol	0.088	0	0.91	0.78
$C_3/C_4/C_5$-alkylbenzenes	0.16	0	1.6	1.4
Ethyl styrene	0.023	0	0.24	0.20
Naphthalene	0.019	0	0.20	0.17
Methyl-naphthalenes	0.0030	0	0.031	0.026
Dimethyl-naphthalenes	0.0041	0	0.043	0.036
Biphenyl	0.0038	0	0.040	0.034
Dimethyl phthalate	0.099	0	1.0	0.88
Diethyl phthalate	0.00028	0	0.0029	0.0025
Dipropyl phthalate	0.0049	30	0.051	0.043
Dibutyl phthalate	0.033	13	0.34	0.29
Di-C_8-alkyl phthalate	0.093	1	0.96	0.82
Bromodinitrobenzene	0.015	0	0.16	0.14
Anthraquinone	0.028	0	0.29	0.25
Methyl myristate	0.020	0	0.20	0.18
Methyl palmitate	0.54	0.1	5.6	4.8
Methyl stearate	0.70	0.2	7.3	6.2
Palmitic acid	7.7	0	80.1	68.6
Diphenyl ethane	0.013	0	0.13	0.11
Ethyl-phenyl-phenyl-ethane	0.020	0	0.21	0.18
Aliphatics	0.46	42	4.8	4.1

[a] Actual cubic meters.

[b] Based on continuous operation for a 24-hr period.

TABLE B-28. PLANT C, CHARACTERISTICS OF EFFLUENT GAS STREAMS ANALYZED BY GAS CHROMATOGRAPHY

GC run numbers	Stack identification	Moisture content volume %	Stack gas temperature °C	Stack gas velocity m/s	Stack gas flow rate m^3/s^a
1	Curing oven on finishing line No. 1 - stack 2 (zone 2)	4.53	94	7.09	2.11
2	Curing oven on finishing line No. 4 - stack 1 (zone 1)	2.50	96	12.33	4.01
3	Curing oven on finishing line No. 4 - stack 2 (zone 2)	3.83	168	6.58	2.14
4	Curing oven on finishing line No. 1 - stack 1 (zone 1)	3.38	58	3.25	0.970
5	Finishing tenter frame No. 1 - stack 3 (zone 3)	6.40	88	10.7	2.98
6	Finishing tenter frame No. 2 - stack 3 (zone 3)	3.03	121	9.44	2.63
7	Finishing tenter frame No. 5 - stack 3 (zone 3)	7.04	129	6.49	1.36
8	Finishing tenter frame No. 4 - stack 3 (zone 3)	4.85	127	11.08	3.09
9	Finishing tenter frame No. 4 - stack 2 (zone 2)	7.95	170	11.62	3.21
10	Finishing tenter frame No. 4 - stack 1 (zone 1)	10.22	168	8.10	2.34
11	Finishing tenter frame No. 3 - stack 1 (zone 1)	3.41	102	5.07	1.34
12	Finishing tenter frame No. 3 - stack 2 (zone 2)	4.93	113	3.99	1.05
13	Finishing tenter frame No. 3 - stack 3 (zone 3)	$\sim$5	126	11.90	3.87
14	Atmospheric Beck No. 12	28.79	68	1.44	0.63
15	Wash box No. 2 - vent A	3.80	34	11.33	7.03
16	Wash box No. 2 - vent B	5.10	36	11.08	6.88
17	Jig vent	3.11	30	7.87	4.89
18	Thermosol dye range - stack A (zone 1)	$\sim$5	70	12.87	3.59
19	Thermosol dye range - stack B (zone 2)	$\sim$5	68	1.71	0.48

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[a] Actual cubic meters per second.

TABLE B-29. PLANT C, NONMETHANE TOTAL HYDROCARBON EMISSION DATA

GC run numbers	Equipment sampled	Operation sampled	Average total hydrocarbon concentration ppm as CH_4[a]	Average methane concentration ppm as CH_4[a]	Nonmethane total hydrocarbon concentration mg/m³ as CH_4[a]	Nonmethane total hydrocarbon emission rate[b] kg/day[c]	Nonmethane total hydrocarbon emission factor mg/kg of fabric
1	Curing oven on finishing line 1 - 2nd zone	Curing	146	110	26	4.7	240
2	Curing oven on finishing line 4 - 1st zone	Curing	76	30	33	11	430
3	Curing oven on finishing line 4 - 2nd zone	Curing	55	40	11	2.0	77
4	Curing oven on finishing line 1 - 1st zone	Curing	183	149	24	2.0	84
5	Finishing tenter frame 1 - 3rd zone	Finishing	206	143	45	12	490
6	Finishing tenter frame 2 - 3rd zone	Drying	68	46	16	3.6	190
7	Finishing tenter frame 5 - 3rd zone	Finishing	10	0	7	0.82	38
8	Finishing tenter frame 4 - 3rd zone	Finishing	1,545	1,042	359	96	3,600
9	Finishing tenter frame 4 - 2nd zone	Finishing	390	305	61	17	640
10	Finishing tenter frame 4 - 1st zone	Finishing	110	79	22	4.4	170
11	Finishing tenter frame 3 - 1st zone	Finishing	403	276	91	11	340
12	Finishing tenter frame 3 - 2nd zone	Finishing	506	267	171	16	500
13	Finishing tenter frame 3 - 3rd zone	Finishing	487	635	0	0	0
14	Atmospheric beck No. 12	Dyeing	1,506	28	1,056	57	–[e]
15	Wash box No. 2 - vent A	Dyeing	13	13	0	0	0
16	Wash box No. 2 - vent B	Dyeing	28	6	16	9.5	440
17	Jig vent	Correction of defect	31	21	7	3.0	–[e]
18	Thermosol dye range - 1st zone	Dyeing	318	281	26	8.1	280
19	Thermosol dye range - 2nd zone	Dyeing	315	152	116	4.8	170

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[a] Conversion factor for ppm $\left(\frac{mL}{m^3}\right)$ to mg/m³ is $\left(\frac{16\ g}{mole}\right)\left(\frac{mole}{22,400\ mL}\right)\left(1,000\ mg/g\right)$.

[b] Based on continuous operation for a 24-hr period.

[c] Emission rate = (mg/m³)(m³/min)(1,440 min/day)(kg/10⁶ mg).

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TABLE B-30. PLANT C, C_1-C_6 HYDROCARBON EMISSION DATA

GC run No.	Equipment sampled	Operation sampled	Number of C_1-C_6 compounds detected[a]	Relative retention time[b]	Average concentration ppm as CH_4
1	Curing oven on finishing line 1 - 2nd zone	Curing	1	2.6	50
2	Curing oven on finishing line 4 - 1st zone	Curing	1	2.8	121
3	Curing oven on finishing line 4 - 2nd zone	Curing	2	0.32 2.8	63 20
4	Curing oven on finishing line 1 - 1st zone	Curing	2	1.4 2.5	4 21
5	Finishing tenter frame 1 - 3rd zone	Finishing	1	2.4	36
6	Finishing tenter frame 2 - 3rd zone	Drying	1	2.4	20
7	Finishing tenter frame 5 - 3rd zone	Finishing	1	2.4	18
8	Finishing tenter frame 4 - 3rd zone	Finishing	0		
9	Finishing tenter frame 4 - 2nd zone	Finishing	0		
10	Finishing tenter frame 4 - 1st zone	Finishing	1	2.4	79
11	Finishing tenter frame 3 - 1st zone	Finishing	2	1.3 2.4	8 71
12	Finishing tenter frame 3 - 2nd zone	Finishing	0		
13	Finishing tenter frame 3 - 3rd zone	Finishing	0		
14	Atmospheric beck No. 12	Dyeing	2	1.3 5.5	8 663
15	Wash box No. 2 - vent A	Dyeing	1	2.6	19
16	Wash box No. 2 - vent B	Dyeing	2	2.6 3.5	27 20
17	Jig vent	Correction of defect	2	2.6 3.8	19 6
18	Thermosol dye range - 1st zone	Dyeing	0		
19	Thermosol dye range - 2nd zone	Dyeing	1	1.5	3

Note.—Blanks indicate that no C_1-C_6 compounds were detected.

[a] Other than CH_4.

[b] Retention time relative to the retention time for methane.

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TABLE B-31. PLANT C, TRACE ELEMENT EMISSION DATA - RUN 1: CURING OF A PERMANENT PRESS FINISH - 2ND ZONE OF CURING OVEN

Element	Concentration in the effluent gas stream, mg/m³	Emission rate, kg/day	Emission factor, mg/kg of fabric
Aluminum	0.00038	0.000070	0.0026
Antimony	0	0	0
Barium	0.0012	0.00022	0.0081
Beryllium	0	0	0
Boron	0.0021	0.00040	0.015
Cadmium	0.00089	0.00016	0.0062
Calcium	0.17	0.031	1.2
Chromium	0.015	0.0028	0.11
Cobalt	0.00082	0.00015	0.0057
Copper	0.0043	0.00079	0.030
Iron	0.058	0.011	0.40
Lead	0.011	0.0021	0.079
Magnesium	0.094	0.017	0.66
Manganese	0.0021	0.00039	0.015
Molybdenum	0	0	0
Nickel	0.0030	0.00055	0.021
Phosphorus	0.0020	0.00037	0.014
Silicon	0.42	0.077	2.9
Silver	0.000021	0.0000038	0.00014
Sodium	9.4	1.7	66
Strontium	0.00012	0.000023	0.00087
Tin	0.019	0.0035	0.13
Titanium	0	0	0
Vanadium	0	0	0
Zinc	0.028	0.0052	0.20

TABLE B-32. PLANT C, TRACE ELEMENT EMISSION DATA - RUN 2: APPLICATION AND DRYING OF PERMANENT PRESS FINISH - 3RD ZONE OF FINISHING TENTER FRAME

Element	Concentration in the effluent gas stream, mg/m³	Emission rate, kg/day	Emission factor, mg/kg of fabric
Aluminum	0.0030	0.00080	0.030
Antimony	0	0	0
Barium	0.0032	0.00084	0.032
Beryllium	0	0	0
Boron	0.0055	0.0015	0.056
Cadmium	0.0011	0.00028	0.011
Calcium	0.0073	0.0020	0.074
Chromium	0.011	0.0029	0.11
Cobalt	0.00089	0.00024	0.0090
Copper	0.0042	0.0011	0.043
Iron	0.082	0.022	0.82
Lead	0.047	0.012	0.47
Magnesium	0.025	0.0066	0.25
Manganese	0.0035	0.00094	0.036
Molybdenum	0.0015	0.00041	0.015
Nickel	0.015	0.0040	0.15
Phosphorus	0.0031	0.00083	0.031
Silicon	1.1	0.29	11
Silver	0.000014	0.0000038	0.00014
Sodium	22	5.9	220
Strontium	0.000077	0.000021	0.00078
Tin	0.25	0.067	2.5
Titanium	0	0	0
Vanadium	0	0	0
Zinc	0.012	0.0031	0.12

TABLE B-33. PLANT C, TRACE ELEMENT EMISSION DATA - RUN 3: DYEING ON A THERMOSOL DYE RANGE - 2ND ZONE OF THERMOSOL OVEN

Element	Concentration in the effluent gas stream, mg/m³	Emission rate, kg/day	Emission factor, mg/kg of fabric
Aluminum	0.0029	0.00084	0.026
Antimony	0	0	0
Barium	0.0041	0.0012	0.036
Beryllium	0	0	0
Boron	0.0064	0.0019	0.056
Cadmium	0.000035	0.000010	0.00031
Calcium	0.093	0.027	0.82
Chromium	0.0032	0.00092	0.028
Cobalt	0.00029	0.000085	0.0026
Copper	0.49	0.14	4.4
Iron	0.060	0.017	0.53
Lead	0.0024	0.00069	0.021
Magnesium	0.081	0.024	0.71
Manganese	0.0020	0.00058	0.017
Molybdenum	0.00027	0.000079	0.0024
Nickel	0	0	0
Phosphorus	0.012	0.0035	0.11
Silicon	0.36	0.11	3.2
Silver	0	0	0
Sodium	230	67	2,000
Strontium	0.00012	0.000035	0.0011
Tin	0.028	0.0082	0.25
Titanium	0	0	0
Vanadium	0	0	0
Zinc	0.0044	0.0013	0.039

TABLE B-34. ESTIMATION OF EMISSION FACTORS FROM SAMPLING DATA - THERMOSOL DYE RANGE AT PLANT C

Emission species	Emission factors estimated for 1st zone of Thermosol dye range, mg/kg of fabric	Emission factors measured for 2nd zone of Thermosol dye range, mg/kg of fabric	Emission factors estimated for total Thermosol dye range, mg/kg of fabric
Particulate matter	87	53	140
Organic compounds			
2-Ethylhexanol	1.3	0.78	2.1
$C_3/C_4/C_5$ alkyl benzenes	2.3	1.4	3.7
Ethyl styrene	0.34	0.20	0.54
Naphthalene	0.28	0.17	0.45
Methyl naphthalenes	0.043	0.026	0.069
Dimethyl naphthalenes	0.059	0.036	0.095
Biphenyl	0.056	0.034	0.090
Dimethyl phthalate	1.4	0.88	2.3
Diethyl phthalate	0.0041	0.0025	0.0066
Dipropyl phthalate	0.071	0.043	0.11
Dibutyl phthalate	0.48	0.29	0.77
Di-C_8-alkyl phthalate	1.4	0.82	2.2
Bromodinitrobenzene	0.23	0.14	0.37
Anthraquinone	0.41	0.25	0.10
Methyl myristate	0.30	0.18	0.48
Methyl palmitate	7.9	4.8	13
Methyl stearate	10	6.2	16
Palmitic acid	110	69	180
Diphenyl ethane	0.18	0.11	0.29
Ethyl-phenyl-phenyl-ethane	0.30	0.18	0.48
Aliphatics	6.8	4.1	11
Nonmethane total hydrocarbons	280	170	450
Trace elements			
Aluminum	0.043	0.026	0.069
Barium	0.059	0.036	0.095
Boron	0.092	0.056	0.15
Cadmium	0.00051	0.00031	0.00082
Calcium	1.4	0.82	2.2
Chromium	0.046	0.028	0.074
Cobalt	0.0043	0.0026	0.0069
Copper	7.2	4.4	12
Iron	0.87	0.53	1.4
Lead	0.035	0.021	0.056
Magnesium	1.2	0.71	1.9
Manganese	0.028	0.017	0.045
Molybdenum	0.0040	0.0024	0.0064
Phosphorus	0.18	0.11	0.29
Silicon	5.3	3.2	8.5
Sodium	3,300	2,000	5,300
Strontium	0.0018	0.0011	0.0029
Tin	0.41	0.25	0.66
Zinc	0.064	0.039	0.10

TABLE B-35. ESTIMATION OF EMISSION FACTORS FROM SAMPLING DATA - FINISHING TENTER FRAME AT PLANT C

Emission species	Emission factors estimated for 1st zone of tenter frame, mg/kg of fabric	Emission factors estimated for 2nd zone of tenter frame, mg/kg of fabric	Emission factors measured for 3rd zone of tenter frame, mg/kg of fabric	Emission factors estimated for total tenter frame, mg/kg of fabric
Particulate matter	1.6	6.0	34	42
Organic compounds				
$C_3/C_4/C_5$ alkyl benzenes	0.15	0.57	3.2	3.9
Ethyl styrene	0.25	0.92	5.2	6.4
Divinyl benzene	0.027	0.10	0.58	0.71
Naphthalene	0.071	0.27	1.5	1.8
Methyl naphthalenes	0.0034	0.013	0.071	0.087
Dimethyl naphthalenes	0.0047	0.018	0.10	0.12
Butyl benzoate	0.0052	0.020	0.11	0.14
Biphenyl	0.0080	0.030	0.17	0.21
Dimethyl phthalate	0.19	0.73	4.1	5.0
Dibutyl phthalate	0.21	0.078	0.44	0.54
Di-C_8-alkyl phthalate	0.0071	0.027	0.15	0.18
C_9-phenols	0.015	0.057	0.32	0.39
t-butyl hydroxyanisole	0.0011	0.0041	0.023	0.028
Bromodinitrobenzene	0.042	0.16	0.88	1.1
Anthraquinone	0.057	0.21	1.2	1.5
Methyl myristate	0.027	0.10	0.57	0.70
Methyl palmitate	0.40	1.5	8.5	10
Methyl stearate	0.52	2.0	11	14
Diphenyl ethane	0.052	0.20	1.1	1.4
Ethyl-phenyl-phenyl-ethane	0.090	0.34	1.9	2.3
Octamethylcyclotetra-siloxane	0.099	0.37	2.1	2.6
Siloxane (dominant ion 267)	0.036	0.14	0.77	0.95
Siloxane (dominant ion 341)	0.017	0.066	0.37	0.45
Aliphatics	0.71	2.7	15	18
Nonmethane total hydrocarbons	3,600	640	170	4,400
Trace elements				
Aluminum	0.0014	0.0053	0.030	0.037
Barium	0.0015	0.0053	0.032	0.039
Boron	0.0026	0.010	0.056	0.069
Cadmium	0.00052	0.0020	0.011	0.014
Calcium	0.0035	0.013	0.074	0.091
Chromium	0.0052	0.020	0.11	0.14
Cobalt	0.00043	0.0016	0.0090	0.011
Copper	0.0020	0.0076	0.043	0.053
Iron	0.039	0.15	0.82	1.0
Lead	0.022	0.084	0.47	0.58
Magnesium	0.012	0.044	0.25	0.31
Manganese	0.0017	0.0064	0.036	0.044
Molybdenum	0.00071	0.0027	0.015	0.018
Nickel	0.0071	0.027	0.15	0.18
Phosphorus	0.0015	0.0055	0.031	0.038
Silicon	0.52	2.0	11	14
Silver	0.0000066	0.000025	0.00014	0.00017
Sodium	10	39	220	270
Strontium	0.000037	0.00014	0.00078	0.00096
Tin	0.12	0.44	2.5	3.1
Zinc	0.0057	0.021	0.12	0.15

TABLE B-36. EMISSION FACTORS MEASURED FOR 1ST AND 2ND ZONES OF A TWO-ZONE TENTER FRAME AT PLANT C

Emission species[a]	Emission factors measured for 1st zone, mg/kg of fabric	Emission factors measured for 2nd zone, mg/kg of fabric	Emission factors for tenter frame (zones 1 and 2), mg/kg of fabric
Particulate matter	13	19	32
Organic compounds			
$C_3/C_4/C_5$-alkyl benzenes	0.68	3.0	3.7
Ethyl styrene	1.2	0.18	1.4
Divinyl benzene	0.099	0.045	0.14
Naphthalene	0.96	0.49	1.5
Methyl naphthalenes	0.066	0.12	0.19
Benzoic acid	0	7.1	7.1
Butyl benzoate	52	436	490
Biphenyl	0.55	0.39	0.94
Methyl biphenyl	0.23	2.1	2.3
Diphenyl ethane	0.60	0	0.60
Ethyl-phenyl-phenyl-ethane	0.98	0	0.98
Di(ethyl-phenyl) ethane	0.35	0	0.35
Dimethyl phthalate	0.15	0.70	0.85
Dipropyl phthalate	0.037	0	0.037
Dibutyl phthalate	0.44	0.29	0.73
Di-C_8-alkyl phthalate	1.4	0.17	1.6
Methyl palmitate	0.095	0.088	0.18
Methyl stearate	0.18	0.15	0.33
Unknown "245"	2.1	0.96	3.1
Unknown "243"	4.0	0.83	4.8
Unknown "241"	0.74	0.47	6.0
Unknown "240"	0.75	1.4	2.2
Unknown "269"	0.099	0.19	0.29
Unknown "239"	0.70	1.7	2.4
Unknown "85"	1.2	2.5	3.7
Oxygenates (e.g., alcohols, alcoholic ethers, etc., estimated C_{12} + above)	5.5	4.4	9.9
Aliphatics	13	13	26
Nonmethane total hydrocarbons	150	350	500
Trace elements			
Aluminum	0.037	0	0.037
Barium	0.036	0.031	0.067
Boron	0.056	0.038	0.094
Cadmium	0.011	0.0047	0.016
Calcium	0.089	2.3	2.4
Chromium	0.43	0.014	0.44
Cobalt	0.020	0.23	0.25
Copper	0.054	0.0032	0.057
Iron	2.1	1.4	3.5
Lead	0.72	0.024	0.74
Magnesium	0.020	0.62	0.64
Manganese	0.037	0.039	0.076
Nickel	0.42	0.039	0.46
Phosphorus	2.6	2.4	5.0
Silicon	0.55	0.25	0.80
Silver	0.0056	0.0045	0.010
Sodium	240	104	340
Strontium	0.00073	0.00078	0.0015
Tin	1.2	1.0	2.2
Zinc	0.28	0.83	1.1

[a] The 1st zone of this tenter frame includes an infrared predryer.

TABLE B-37. ESTIMATION OF EMISSION FACTORS FROM SAMPLING DATA - CURING OVEN AT PLANT C

Emission species	Emission factors estimated for 1st zone of curing oven,[a] mg/kg of fabric	Emission factors measured for 2nd zone of curing oven,[b] mb/kg of fabric	Emission factors estimated for total curing oven,[c] mg/kg of fabric
Particulate matter	101	18	120
Organic compounds			
$C_3/C_4/C_5$-alkyl benzenes	2.6	0.46	3.1
Ethyl styrene	5.2	0.93	6.1
Divinyl benzene	0.54	0.097	0.64
Dichlorobenzene	0.054	0.0096	0.064
Naphthalene	2.5	0.45	3.0
Methyl naphthalenes	0.22	0.040	0.26
Dimethyl naphthalenes	0.43	0.077	0.51
Butyl benzoate	8.4	1.5	9.9
Biphenyl	4.2	0.75	5.0
Dimethyl phthalate	51	9.2	60
Dibutyl phthalate	1.5	0.27	1.8
Di-C_8-alkyl phthalate	0.31	0.055	0.37
C_8-phenols	0.78	0.14	0.92
C_9-phenols	3.5	0.63	4.1
Bromodinitrobenzene	9.5	1.7	11
Anthraquinone	11	1.9	13
Methyl myristate	3.1	0.55	3.7
Methyl palmitate	61	11	72
Methyl stearate	78	14	92
Palmitic acid	36	6.4	42
Diphenyl ethane	2.6	0.46	3.1
Ethyl-phenyl-phenyl-ethane	3.7	0.66	4.4
Aliphatics	25	4.4	29
Nonmethane total hydrocarbons	430[d]	77	510
Trace elements			
Aluminum	0.015	0.0026	0.018
Barium	0.045	0.0081	0.053
Boron	0.084	0.015	0.099
Cadmium	0.035	0.0062	0.041
Calcium	6.7	1.2	7.9
Chromium	0.61	0.11	0.72
Cobalt	0.032	0.0057	0.038
Copper	0.17	0.030	0.20
Iron	2.2	0.40	2.6
Lead	0.44	0.079	0.52
Magnesium	3.7	0.66	4.4
Manganese	0.084	0.015	0.099
Nickel	0.12	0.021	0.14
Phosphorus	0.078	0.014	0.092
Silicon	16	2.9	19
Silver	0.00078	0.00014	0.00092
Sodium	370	66	440
Strontium	0.0049	0.00087	0.0058
Tin	0.73	0.13	0.86
Zinc	1.1	0.20	1.3

TABLE B-38. PLANT D, CHARACTERISTICS OF THE EFFLUENT GAS STREAMS SAMPLED BY MRC

Effluent parameter	Units	Run 1: Curing oven attached to finishing tenter frame No. 2	Run 2: 2nd zone of finishing tenter frame No. 2	Run 3: 1st zone of finishing tenter frame No. 2
Oxygen (O_2) content	Volume %	17	20.7	17.5
Carbon dioxide (CO_2) content	Volume %	1	0.5	2.2
Nitrogen (N_2) content	Volume %	82	78.8	80.3
Moisture (H_2O) content	Volume %	6.61	5.41	5.75
Dry molecular weight of stack gas	g/mole	26.0	28.9	29.1
Molecular weight of stack gas	g/mole	25.5	28.3	28.4
Stack gas temperature (average)	°C	168	49	157
Stack gas temperature (range)	°C	161 to 173	43 to 54	154 to 158
Average stack gas velocity	m/s	15.9	1.79	1.95
Average stack gas flow rate (actual)	m^3/s	4.64	6.49	3.00
Average stack gas flow rate (standard conditions)	m^3/s	2.88	5.54	1.93

TABLE B-39. PLANT D, PARTICULATE EMISSION DATA

Run No.	Operation sampled	Concentration of particulate in effluent gas stream, mg/m^3[a]	Particulate contribution to the total emissions, weight %	Emission rate,[b] kg/day	Emission factor mg/kg of fabric
1	Curing of a finish in curing oven No. 2	1.99	0.00028	0.80	31
2	Finishing on tenter frame No. 2 (2nd zone)	0.992	0.000092	0.56	19
3	Finishing on tenter frame No. 2 (1st zone)	1.62	0.00020	0.42	13

[a] Actual cubic meters.

[b] Based on continuous operation for a 24-hr day.

TABLE B-40. PLANT D, EMISSION DATA FOR ORGANIC COMPOUNDS - RUN 1: CURING OF A FINISH IN CURING OVEN NO. 2

Organic species	Concentration in the effluent gas stream, mg/m^3 [a]	Percentage of compound collected in the particulate phase, weight %	Emission rate,[b] kg/day	Emission factor mg/kg of fabric
C_3/C_4/C_5-alkylbenzenes	4.4	0	1.8	69
Ethyl styrene	0.20	0	0.079	3.1
Naphthalene	0.35	0	0.14	5.5
Methyl naphthalene	0.043	0	0.017	0.68
Benzoic acid	8.5	0	3.4	133
Butyl benzoate	116	0	47	1,832
Biphenyl	0.13	0	0.053	2.1
Methyl biphenyl	0.53	0	0.21	8.3
Dimethyl phthalate	0.041	0	0.016	0.64
Dibutyl phthalate	0.24	0	0.096	3.8
Di-C_8 alkyl phthalate	0.064	8	0.025	1.0
Methyl palmitate	0.0023	0	0.00093	0.036
Methyl stearate	0.0053	0	0.0021	0.084
Dichloronitroaniline	0.61	0	0.24	9.6
Aliphatics	2.7	1	1.1	43
Oxygenates (e.g., alcohols, alcoholic ethers, etc., estimated C_{12} and above)	1.0	0	0.41	16
Unknown "245"	0.15	0	0.061	2.4
Unknown "243"	0.13	0	0.051	2.0
Unknown "241"	0.087	0	0.035	1.4
Unknown "240"	0.26	0	0.10	4.1
Unknown "269"	0.027	0	0.011	0.43
Unknown "239"	0.36	0	0.14	5.6
Unknown "85"[d]	0.41	0	0.16	6.4

[a] Actual cubic meters.

[b] Based on continuous operation for a 24-hr period.

TABLE B-41. PLANT D, EMISSION DATA FOR ORGANIC COMPOUNDS - RUN 2: FINISHING ON TENTER FRAME NO. 2 (EXHAUST FROM 2ND ZONE)

Organic species	Concentration in the effluent gas stream, mg/m³[a]	Percentage of compound collected in the particulate phase, weight %	Emission rate,[b] kg/day	Emission factor mg/kg of fabric
$C_3/C_4/C_5$-alkylbenzenes	0.15	0	0.088	3.0
Ethyl styrene	0.0096	0	0.0054	0.18
Divinyl benzene	0.0024	0	0.0013	0.045
Naphthalene	0.026	0	0.015	0.49
Methyl naphthalene	0.0061	0	0.0034	0.12
Benzoic acid	0.37	0	0.21	7.1
Butyl benzoate	23	0	13	436
Biphenyl	0.020	0	0.011	0.39
Methyl biphenyl	0.11	0	0.063	2.1
Dimethyl phthalate	0.037	0	0.021	0.70
Dibutyl phthalate	0.016	0	0.0087	0.29
Di-C_8 alkyl phthalate	0.0088	0	0.0049	0.17
Methyl palmitate	0.0047	33	0.0026	0.088
Methyl stearate	0.0081	0	0.0046	0.15
Dichloronitroaniline	0.16	0	0.088	3.0
Aliphatics	0.68	0	0.38	13
Oxygenates (e.g., alcohols, alcoholic ethers, etc., estimated C_{12} and above)	0.23	0	0.13	4.4
Unknown "245"	0.051	0	0.028	0.96
Unknown "243"	0.044	0	0.025	0.83
Unknown "241"	0.025	0	0.014	0.47
Unknown "240"	0.073	0	0.041	1.4
Unknown "269"	0.0099	0	0.0056	0.19
Unknown "239"	0.090	0	0.050	1.7
Unknown "85"	0.13	0	0.073	2.5

[a] Actual cubic meters.

[b] Based on continuous operation for a 24-hr period.

TABLE B-42. PLANT D, EMISSION DATA FOR ORGANIC COMPOUNDS - RUN 3: FINISHING ON TENTER FRAME NO. 2 (EXHAUST FROM 1ST ZONE

Organic species	Concentration in the effluent gas stream, mg/m³[a]	Percentage of compound collected in the particulate phase, weight %	Emission rate,[b] kg/day	Emission factor mg/kg of fabric
$C_3/C_4/C_5$-alkylbenzenes	0.085	0	0.022	0.68
Ethyl styrene	0.15	0	0.039	1.2
Divinyl benzene	0.012	0	0.0032	0.099
Naphthalene	0.12	0	0.031	0.96
Methyl naphthalene	0.0082	0	0.0021	0.066
Butyl benzoate	6.5	0	1.7	52
Biphenyl	0.068	0	0.018	0.55
Methyl biphenyl	0.028	0	0.0073	0.23
Diphenyl ethane	0.075	0	0.019	0.60
Ethyl-phenyl-phenyl-ethane	0.12	0	0.032	0.98
Di(ethyl phenyl)ethane	0.042	0	0.011	0.35
Dimethyl phthalate	0.018	0	0.0050	0.15
Dipropyl phthalate	0.0044	0	0.0012	0.037
Dibutyl phthalate	0.052	0	0.014	0.44
Di-C_8 alkyl phthalate	0.17	42	0.045	1.4
Methyl palmitate	0.011	0	0.0031	0.095
Methyl stearate	0.022	0	0.0060	0.18
Dichloronitroaniline	0.030	0	0.0081	0.25
Aliphatics	1.5	8	0.42	13
Oxygenates (e.g., alcohols, alcoholic ethers, etc., estimated C_{12} and above)	0.66	0	0.18	5.5
Unknown "245"	0.26	0	0.069	2.1
Unknown "243"	0.48	0	0.13	4.0
Unknown "241"	0.089	0	0.024	0.74
Unknown "240"	0.090	0	0.024	0.75
Unknown "269"	0.012	0	0.0032	0.099
Unknown "239"	0.084	0	0.023	0.70
Unknown "85"	0.14	0	0.038	1.2

[a] Actual cubic meters.

[b] Based on continuous operation for a 24-hr period.

TABLE B-43. PLANT D, TRACE ELEMENT EMISSION DATA - RUN 1: CURING OF A FINISH IN CURING OVEN NO. 2

Element	Concentration in the effluent gas stream, mg/m^3[a]	Emission rate,[b] kg/day	Emission factor mg/kg of fabric
Aluminum	-[c]	0	0
Antimony	-[c]	0	0
Barium	0.000041	0.000016	0.00064
Beryllium	-[c]	0	0
Boron	0.00030	0.00012	0.0047
Cadmium	0.0010	0.00041	0.016
Calcium	0.20	0.081	3.2
Chromium	0.0013	0.00052	0.020
Cobalt	0.00019	0.000077	0.0030
Copper	0.00060	0.00024	0.0094
Iron	0.047	0.019	0.73
Lead	0.00042	0.00017	0.0067
Magnesium	0.099	0.040	1.6
Manganese	0.0078	0.0031	0.12
Molybdenum	-[c]	0	0
Nickel	0.00053	0.00021	0.0072
Phosphorus	0.065	0.026	1.0
Silicon	0.49	0.20	7.8
Silver	-[c]	0	0
Sodium	14.7	5.9	230
Strontium	0.00010	0.000041	0.0016
Tin	0.071	0.028	1.1
Titanium	-[c]	0	0
Vanadium	-[c]	0	0
Zinc	0.0043	0.0017	0.068

[a] Actual cubic meters.

[b] Based on continuous operation for a 24-hr period.

[c] Below detection limit.

TABLE B-44. PLANT D, TRACE ELEMENT EMISSION DATA - RUN 2: FINISHING ON TENTER FEAME NO. 2 (EXHAUST FROM 2ND ZONE)

Element	Concentration in the effluent gas stream, mg/m³ [a]	Emission rate, [b] kg/day	Emission factor mg/kg of fabric
Aluminum	- [c]	0	0
Antimony	- [c]	0	0
Barium	0.0016	0.00092	0.031
Beryllium	- [c]	0	0
Boron	0.0021	0.0011	0.038
Cadmium	0.00025	0.00014	0.0047
Calcium	0.12	0.067	2.3
Chromium	0.00075	0.00042	0.014
Cobalt	0.012	0.0067	0.23
Copper	0.00017	0.000096	0.0032
Iron	0.076	0.042	1.4
Lead	0.0013	0.00071	0.024
Magnesium	0.033	0.018	0.62
Manganese	0.0020	0.0011	0.039
Molybdenum	- [c]	0	0
Nickel	0.0020	0.0012	0.039
Phosphorus	0.13	0.070	2.4
Silicon	0.013	0.0072	0.25
Silver	0.00024	0.00013	0.0045
Sodium	5.5	3.1	104
Strontium	0.000041	0.000023	0.00078
Tin	0.054	0.030	1.0
Titanium	- [c]	0	0
Vanadium	- [c]	0	0
Zinc	0.044	0.025	0.83

[a] Actual cubic meters.

[b] Based on continuous operation for a 24-hr period.

[c] Below detection limit.

TABLE B-45. PLANT D, TRACE ELEMENT EMISSION DATA - RUN 3: FINISHING ON TENTER FRAME NO. 2 (EXHAUST FROM 1ST ZONE)

Element	Concentration in the effluent gas stream, mg/m³[a]	Emission rate,[b] kg/day	Emission factor mg/kg of fabric
Aluminum	0.0046	0.0012	0.037
Antimony	-[c]	0	0
Barium	0.0044	0.0012	0.036
Beryllium	-[c]	0	0
Boron	0.0070	0.0018	0.056
Cadmium	0.0013	0.00035	0.011
Calcium	0.011	0.0029	0.089
Chromium	0.054	0.014	0.43
Cobalt	0.0025	0.00065	0.020
Copper	0.0068	0.00018	0.054
Iron	0.27	0.069	2.1
Lead	0.090	0.023	0.72
Magnesium	0.0025	0.00065	0.020
Manganese	0.0046	0.0012	0.037
Molybdenum	-[c]	0	0
Nickel	0.053	0.014	0.43
Phosphorus	0.33	0.085	2.6
Silicon	0.068	0.018	0.55
Silver	0.00073	0.00018	0.0056
Sodium	30	7.9	240
Strontium	0.000091	0.000024	0.00073
Tin	0.15	0.038	1.2
Titanium	-[c]	0	0
Vanadium	-[c]	0	0
Zinc	0.035	0.0091	0.28

---

[a] Actual cubic meters.

[b] Based on continuous operation for a 24-hr period.

[c] Below detection limit.

TABLE B-46. PLANT D, NONMETHANE TOTAL HYDROCARBON (THC) EMISSION DATA

THC run No.	Equipment sampled	Average total hydrocarbon concentration, ppm as CH_4[a]	Average methane concentration, ppm as CH_4[a]	Nonmethane total hydrocarbon concentration, mg/m³ as CH_4[a]	Nonmethane total hydrocarbon emission rate,[b] kg/day[c]	Nonmethane total hydrocarbon emission factor mg/kg of fabric
1	2nd zone of tenter frame No. 2	109	0	78	44	1.4
2	2nd zone of tenter frame No. 2	10	4	4	2.2	0.073
3	Curing oven on tenter frame No. 2	26	19	5	2.0	0.065
4	1st zone of tenter frame No. 2	30	0	21	5.4	0.18
5	1st zone of tenter frame No. 2	37	14	16	4.1	0.13
6	Curing oven on tenter frame No. 2	29	19	7	2.8	0.091
7	Curing oven on tenter frame No. 2	54	9	32	13	0.40
8	2nd zone of tenter frame No. 2	5	1	3	1.7	0.052
9	1st zone of tenter frame No. 2	40	15	18	4.7	0.14
10	Curing oven on tenter frame No. 2	60	14[d]	33	13	0.41
11	2nd zone of tenter frame No. 2	9	2[d]	5	2.5	0.087
12	2nd zone of tenter frame No. 2	12	2[d]	7	3.9	0.12
	Average for 1st zone of tenter frame No. 2	37	10	19	4.9	0.15
	Average for 2nd zone of tenter frame No. 2	29	2	19	11	0.35
	Average for curing oven on tenter frame No. 2	42	14	20	8.0	0.24

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[a] Conversion factor for ppm $\left(\frac{mL}{m^3}\right)$ as CH_4 to mg/m³ as CH_4 is $\left(16\ g/mole\right)\left(\frac{mole}{22,400\ mL}\right)\left(1,000\ mg/g\right)$

[b] Based on continuous operation for a 24-hr period.

[c] Emission rate = (mg/m³)(m³/min)(1,440 min/day)(kg/10⁶ mg).

[d] No methane concentrations were determined on the day of these runs due to technical difficulties, therefore the average values are used.

TABLE B-47. PLANT D, C_1-C_6 HYDROCARBON EMISSION DATA

GC run No.	Equipment sampled	Operation sampled	Number of C_1-C_6 compounds detected[a]	Relative retention time[b]	Average concentration, ppm as CH_4
1	2nd zone of tenter frame No. 2	Finishing	0		
2	1st zone of tenter frame No. 2	Finishing	0		
3	1st zone of tenter frame No. 2	Finishing	1	2.2	14
4	2nd zone of tenter frame No. 2	Finishing	1	2.3	18
5	Curing oven on tenter frame No. 2	Curing	1	2.2	15
6	1st zone of tenter frame No. 2	Finishing	2	2.7 3.9	21 4
7	Curing oven on tenter frame No. 2	Curing	4	1.3 2.5 2.9 3.8	9 20 15 16
8	2nd zone of tenter frame No. 2	Finishing	1	2.5	6

Note.—Blanks indicate that no C_1-C_6 compounds were detected.

[a] Other than CH_4.

[b] Retention time relative to the retention time for CH_4.

APPENDIX C

DERIVATION OF SOURCE SEVERITY EQUATIONS

SUMMARY OF SEVERITY EQUATIONS FOR AIR POLLUTANTS

The severity (S) of pollutants may be calculated using the mass emission rate (Q), the height of the emissions (H), and the threshold limit value (TLV) (for noncriteria pollutants) [24]. The equations summarized in Table C-1 are developed in detail in this appendix.

TABLE C-1. POLLUTANT SEVERITY EQUATIONS FOR ELEVATED POINT SOURCES

Pollutants	Severity equation
Particulate	$S_P = \frac{70\ Q}{H^2}$
Hydrocarbon	$S_{HC} = \frac{162\ Q}{H^2}$
Other	$S_A = \frac{5.5\ Q}{TLV \bullet H^2}$

DERIVATION OF χ_{max} FOR USE WITH U.S. AVERAGE CONDITIONS

The most widely accepted formula for predicting downwind ground level concentrations from a point source is [21].

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \qquad \text{(C-1)}$$

where χ = downwind ground level concentration at reference coordinate x and y with emission height of H, g/m^3
Q = mass emission rate, g/s
π = 3.14
σ_y = standard deviation of horizontal dispersion, m
σ_z = standard deviation of vertical dispersion, m
u = wind speed, m/s
y = horizontal distance from centerline of dispersion, m
H = height of emission release, m
x = downwind dispersion distance from source of emission release, m

We assume that χ_{max} occurs when x is much greater than 0 and y equals 0. For a given stability class, standard deviations of horizontal and vertical dispersion have often been expressed as a function of downwind distance by power law relationships as follows [53]:

$$\sigma_y = ax^b \tag{C-2}$$

$$\sigma_z = cx^d + f \tag{C-3}$$

Values for a, b, c, d, and f are given in Tables C-2 [54] and C-3. Substituting these general equations into Equation D-1 yields

$$\chi = \frac{Q}{ac\pi ux^{b+d} + a\pi ufx^b} \exp\left[-\frac{H^2}{2(cx^d + f)^2}\right] \tag{C-4}$$

Assuming that χ_{max} occurs at x less than 100 m and the stability class is C, then f equals 0 and Equation C-4 becomes

$$\chi = \frac{Q}{ac\pi ux^{b+d}} \exp\left[\frac{-H^2}{2c^2x^{2d}}\right] \tag{C-5}$$

For convenience, let

$$A_R = \frac{Q}{ac\pi u} \text{ and } B_R = \frac{-H^2}{2c^2}$$

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[53] Martin, D. O., and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Presented at the 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minnesota, June 23-27, 1968. 18 pp.

[54] Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions for the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment, 3(6): 688-689, 1969.

TABLE C-2. VALUES OF a FOR THE COMPUTATION OF σ_y[a] [55]

Stability class	a
A	0.3658
B	0.2751
C	0.2089
D	0.1471
E	0.1046
F	0.0722

[a] For Equation C-2: $\sigma_y = ax^b$

where x = downwind distance
b = 0.9031 (from Reference 155)

TABLE C-3. VALUES OF THE CONSTANTS USED TO ESTIMATE VERTICAL DISPERSION[a] [53]

Usable range, m	Stability class	Coefficient		
		c_1	d_1	f_1
>1,000	A	0.00024	2.094	-9.6
	B	0.055	1.098	2.0
	C	0.113	0.911	0.0
	D	1.26	0.516	-13
	E	6.73	0.305	-34
	F	18.05	0.18	-48.6
		c_2	d_2	f_2
100 to 1,000	A	0.0015	1.941	9.27
	B	0.028	1.149	3.3
	C	0.113	0.911	0.0
	D	0.222	0.725	-1.7
	E	0.211	0.678	-1.3
	F	0.086	0.74	-0.35
		c_3	d_3	f_3
<100	A	0.192	0.936	0
	B	0.156	0.922	0
	C	0.116	0.905	0
	D	0.079	0.881	0
	E	0.063	0.871	0
	F	0.053	0.814	0

[a] For Equation C-3: $\sigma_z = cx^d + f$

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[55] Tadmor, J., and Y. Gur. Analytical Expressions for the Vertical and Lateral Dispersion Coefficients in Atmospheric Diffusion. Atmospheric Environment, 3(6):688-689, 1969.

so that Equation C-5 reduces to

$$\chi = A_R x^{-(b+d)} \exp\left[\frac{B_R}{x^{2d}}\right] \qquad \text{(C-6)}$$

Taking the first derivative of Equation C-6

$$\frac{d\chi}{dx} = A_R \left\{ x^{-b-d}\left(\exp\left[B_R x^{-2d}\right]\right)\left(-2dB_R x^{-2d-1}\right) + \exp\left[B_R x^{-2d}\right]\left(-b-d\right)x^{-b-d-1} \right\} \qquad \text{(C-7)}$$

and setting this equal to zero (to determine the roots which give the minimum and maximum conditions of χ with respect to x) yields

$$\frac{d\chi}{dx} = 0 = A_R x^{-b-d-1}\left[\exp\left(B_R x^{-2d}\right)\right]\left(-2dB_R x^{-2d} - b - d\right) \qquad \text{(C-8)}$$

Since we define that $x \neq 0$ or ∞ at χ_{max}, the following expression must be equal to 0.

$$-2dB_R x^{-2d} - d - b = 0 \qquad \text{(C-9)}$$

or

$$(b+d)x^{2d} = -2dB_R \qquad \text{(C-10)}$$

or

$$x^{2d} = \frac{-2dB_R}{b+d} = \frac{2dH^2}{2c^2(b+d)} \qquad \text{(C-11)}$$

or

$$x^{2d} = \frac{dH^2}{c^2(b+d)} \qquad \text{(C-12)}$$

Hence

$$x = \left(\frac{dH^2}{c^2(b+d)}\right)^{1/2d} \text{ at } \chi_{max} \qquad \text{(C-13)}$$

Thus Equations C-2 and C-3 (at f = 0) become

$$\sigma_y = a\left(\frac{dH^2}{c^2(d+b)}\right)^{b/2d} \qquad \text{(C-14)}$$

$$\sigma_z = c\left[\frac{dH^2}{c^2(b+d)}\right]^{d/2d} = \left(\frac{dH^2}{b+d}\right)^{1/2} \qquad \text{(C-15)}$$

The maximum will be determined for U.S. average conditions of stability. According to Gifford [56], this is when σ_y equals σ_z.

Since b equals 0.9031, and upon inspection of Table C-2 under U.S. average conditions, σ_y equals σ_z, it can be seen that 0.881 is less than or equal to d which is less than or equal to 0.905 (class C stability[a]). Thus, it can be assumed that b is nearly equal to d or in Equations C-14 and C-15 or

$$\sigma_z = \frac{H}{\sqrt{2}} \qquad \text{(C-16)}$$

and

$$\sigma_y = \frac{a}{c}\,\frac{H}{\sqrt{2}} \qquad \text{(C-17)}$$

Under U.S. average conditions, σ_y equals σ_z and a approximates c if b approximates d and f equals 0 (between class C and D, but closer to belonging in class C).

Then

$$\sigma_y = \frac{H}{\sqrt{2}} \qquad \text{(C-18)}$$

Substituting for σ_y from Equation C-18 and for σ_z from Equation C-16 into Equation C-1 and letting y equal 0

$$\chi_{max} = \frac{2\,Q}{\pi u H^2} \exp\left[-\,\frac{1}{2}\left(\frac{H\sqrt{2}}{H}\right)^2\right] \qquad \text{(C-19)}$$

or

$$\chi_{max} = \frac{2\,Q}{\pi e u H^2} \qquad \text{(C-20)}$$

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[a] The values given in Table C-3 are mean values for stability class. Class C stability describes these coefficients and exponents, only within about a factor of two.

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[56] Gifford, F. A., Jr. An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Chapter 3, D. A. Slade, ed. Publication No. TID-24190, U.S. Atomic Energy Commission Technical Information Center, Oak Ridge, Tennessee, July 1968. p. 113.

For U.S. average conditions, u equals 4.47 m/s so that Equation C-20 reduces to

$$\chi_{max} = \frac{0.0524\ Q}{H^2} \qquad \text{(C-21)}$$

DEVELOPMENT OF SOURCE SEVERITY EQUATIONS

Source severity, S, has been defined as follows:

$$S = \frac{\overline{\chi}_{max}}{F} \qquad \text{(C-22)}$$

where $\overline{\chi}_{max}$ = time-averaged maximum ground level concentration
F = hazard factor; for criteria pollutants, F = AAQS; for noncriteria pollutants, F = TLV • 8/24 • 1/100.

Noncriteria Emissions

The value of $\overline{\chi}_{max}$ may be derived from χ_{max}, and undefined "short-term" concentration. An approximation for longer term concentration may be made as follows:

For a 24-hr time period,

$$\overline{\chi}_{max} = \chi_{max} \left(\frac{t_o}{t}\right)^{0.17} \qquad \text{(C-23)}$$

where t_o = instantaneous (i.e., 3-min) averaging time
t = averaging time period used (i.e., 24 hr or 1,440 min)

Hence

$$\overline{\chi}_{max} = \chi_{max} \left(\frac{3\ \text{min}}{1{,}440\ \text{min}}\right)^{0.17} \qquad \text{(C-24)}$$

$$\overline{\chi}_{max} = \chi_{max}\ (0.35) \qquad \text{(C-25)}$$

Since the hazard factor is defined and derived from TLV values as follows:

$$F = (\text{TLV}) \left(\frac{8}{24}\right)\left(\frac{1}{100}\right) \qquad \text{(C-26)}$$

$$F = (3.33 \times 10^{-3})\ \text{TLV} \qquad \text{(C-27)}$$

then the severity factor, S_a, is defined as

$$S_a = \frac{\overline{\chi}_{max}}{F} = \frac{0.35\ \chi_{max}}{(3.33 \times 10^{-3})\ \text{TLV}} \qquad \text{(C-28)}$$

$$S_a = \frac{105\ \chi_{max}}{TLV} \qquad \text{(C-29)}$$

If a weekly averaging period is used, then

$$\bar{\chi}_{max} = \chi_{max} \left(\frac{3}{10,080}\right)^{0.17} \qquad \text{(C-30)}$$

or

$$\bar{\chi}_{max} = 0.25\ \chi_{max} \qquad \text{(C-31)}$$

and

$$F = (TLV)\left(\frac{40}{168}\right)\left(\frac{1}{100}\right) \qquad \text{(C-32)}$$

$$F = (2.38 \times 10^{-3})TLV \qquad \text{(C-33)}$$

and the severity factor, S_a, is

$$S_a = \frac{\bar{\chi}_{max}}{F} = \frac{0.25\ \chi_{max}}{(2.38 \times 10^{-3})TLV} \qquad \text{(C-34)}$$

or

$$S_a = \frac{105\ \chi_{max}}{TLV} \qquad \text{(C-35)}$$

which is entirely consistent, since the TLV is being corrected for a different exposure period.

Therefore, the severity can be derived from χ_{max} directly without regard to averaging time for noncriteria emissions. Thus, combining Equations C-35 and C-21, for elevated sources, gives

$$S_a = \frac{5.5\ Q}{TLV \bullet H^2} \qquad \text{(C-36)}$$

Criteria Emissions

For the criteria pollutants, established standards may be used as F values in Equation C-22. These are given in Table C-4 [24]. However, Equation C-23 must be used to give the appropriate averaging period. These equations are developed for elevated sources using Equation C-21.

TABLE C-4. SUMMARY OF NATIONAL AMBIENT AIR QUALITY STANDARDS [24]

Pollutant	Averaging time	Primary standards, $\mu g/m^3$	Secondary standards, $\mu g/m^3$
Particulate matter	Annual (geometric mean)	75	60[a]
	24-hr[b]	260	160
SO_x	Annual (arithmetic mean)	80	60
	24-hr[b]	365	260[c]
	3-hr[b]	-[d]	1,300
CO	8-hr[b]	10,000	10,000
	1-hr[b]	40,000	40,000
Nitrogen dioxide	Annual (arithmetic mean)	100	100
Photochemical oxidants	1-hr[b]	160	160
Hydrocarbons (nonmethane)	3-hr (6 a.m. to 9 a.m.)	160[e]	160

[a] The secondary annual standard (60 $\mu g/m^3$) is a guide for assessing implementation plans to achieve the 24-hr secondary standard.

[b] Not to be exceeded more than once per year.

[c] The secondary annual standard (260 $\mu g/m^3$) is a guide for assessing implementation plans to achieve the annual standard.

[d] No standard exists.

[e] There is no primary ambient air quality standard for hydrocarbons. The value of 160 $\mu g/m^3$ used for hydrocarbons in this report is an EPA-recommended guideline for meeting the primary ambient air quality standard for oxidants.

Carbon Monoxide Severity--
The primary standard for CO is reported for a 1-hr averaging time. Therefore

$$t = 60 \text{ min}$$

$$t_o = 3 \text{ min}$$

$$\bar{\chi}_{max} = \chi_{max} \left(\frac{3}{60}\right)^{0.17} \tag{C-37}$$

$$= \frac{2\,Q}{\pi e u H^2} \left(\frac{3}{60}\right)^{0.17} \tag{C-38}$$

$$= \frac{2\,Q}{(3.14)(2.72)(4.5)H^2}\ 0.6 \tag{C-39}$$

$$\bar{\chi}_{max} = \frac{0.052\,Q}{H^2}\ 0.6 \tag{C-40}$$

$$\bar{\chi}_{max} = \frac{(3.12 \times 10^{-2})Q}{H^2} \tag{C-41}$$

$$\text{Severity, } S = \frac{\overline{X}_{max}}{F} \qquad \text{(C-42)}$$

Setting F equal to the primary AAQS for CO or 0.04 g/m^3 yields

$$S = \frac{\overline{X}_{max}}{F} = \frac{(3.12 \times 10^{-2})Q}{0.04\ H^2} \qquad \text{(C-43)}$$

or

$$S_{CO} = \frac{0.78\ Q}{H^2} \qquad \text{(C-44)}$$

Hydrocarbon Severity--
The primary standard for nonmethane hydrocarbons is reported for a 3-hr averaging time.

$$t = 180 \text{ min}$$

$$t_0 = 3 \text{ min}$$

$$\overline{X}_{max} = X_{max} \left(\frac{3}{180}\right)^{0.17} \qquad \text{(C-45)}$$

$$= 0.5\ X_{max} \qquad \text{(C-46)}$$

$$= \frac{(0.5)(0.052)Q}{H^2} \qquad \text{(C-47)}$$

$$\overline{X}_{max} = \frac{0.026\ Q}{H^2} \qquad \text{(C-48)}$$

For nonmethane hydrocarbons, the concentraiton of 1.6×10^{-4} g/m^3 has been issued as a guideline for achieving oxidant standards. Therefore,

$$S = \frac{\overline{X}_{max}}{F} = \frac{0.026\ Q}{1.6 \times 10^{-4}\ H^2} \qquad \text{(C-49)}$$

or

$$S_{HC} = \frac{162.5\ Q}{H^2} \qquad \text{(C-50)}$$

Particulate Severity--
The primary standard for particulate is reported for a 24-hr averaging time.

$$\bar{X}_{max} = X_{max}\left(\frac{3}{1,440}\right)^{0.17} \quad \text{(C-51)}$$

$$= \frac{(0.35)(0.052)Q}{H^2} \quad \text{(C-52)}$$

$$\bar{X}_{max} = \frac{0.0182\ Q}{H^2} \quad \text{(C-53)}$$

For particulates, F equals the primary AAQS or 2.6 x 10^{-4} g/m³, and

$$S = \frac{\bar{X}_{max}}{F} = \frac{0.0182\ Q}{(2.6 \times 10^{-4})H^2} \quad \text{(C-54)}$$

$$S_p = \frac{70\ Q}{H^2} \quad \text{(C-55)}$$

SO$_x$ Severity--
The primary standard for SO$_x$ is reported for a 24-hr averaging time. Using t = 1,440 minutes and proceeding as before:

$$\bar{X}_{max} = \frac{0.0182\ Q}{H^2} \quad \text{(C-56)}$$

The primary AAQS for SO$_x$ is 3.65 x 10^{-4} g/m³. Therefore,

$$S = \frac{\bar{X}_{max}}{F} = \frac{0.0182\ Q}{(3.65 \times 10^{-4})H^2} \quad \text{(C-57)}$$

or

$$S_{SO_x} = \frac{50\ Q}{H^2} \quad \text{(C-58)}$$

NO$_x$ Severity--
Since NO$_x$ has a primary standard with a 1-yr averaging time, the X_{max} correction equation cannot be used. As an alternative, the following equation is used:

$$\bar{X} = \frac{2.03\ Q}{\sigma_z u x} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \quad \text{(C-59)}$$

A difficulty arises, however, because a distance x, from emission point to receptor, is included; hence, the following rationale is used:

$$X_{max} = \frac{2\ Q}{\pi e u H^2} \quad \text{(C-20)}$$

Equation C-20, shown earlier is valid for neutral conditions or when σ_z approximately equals σ_y.

This maximum occurs when

$$H = \sqrt{2}\sigma_z \tag{C-60}$$

and since, under these conditions,

$$\sigma_z = ax^b \tag{C-61}$$

then the distance, x_{max}, where the maximum concentration occurs is

$$x_{max} = \left(\frac{H}{\sqrt{2}a}\right)^{1/b} \tag{C-62}$$

For class C conditions, a = 0.113 and b = 0.911. Substituting these values into Equation C-62 yields:

$$x_{max} = \frac{H^{1.098}}{0.16} = 7.5\ H^{1.098} \tag{C-63}$$

Since

$$\sigma_z = 0.113\ x_{max}{}^{0.911} \tag{C-64}$$

and

$$u = 4.5\ m/s$$

and letting $x = x_{max}$, Equation C-59 becomes

$$\bar{X}_{max} = \frac{4\ Q}{x_{max}{}^{1.911}} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \tag{C-65}$$

where

$$\frac{4\ Q}{x_{max}{}^{1.911}} = \frac{4\ Q}{(7.5\ H^{1.098})^{1.911}} \tag{C-66}$$

Therefore,

$$\bar{X}_{max} = \frac{0.085\ Q}{H^{2.1}} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \tag{C-67}$$

As noted above,

$$\sigma_z = 0.113\ x^{0.911} \qquad \text{(C-67)}$$

Substituting for x yields

$$\sigma_z = 0.113(7.5\ H^{1.1})^{0.911} \qquad \text{(C-68)}$$

or

$$\sigma_z = 0.71\ H \qquad \text{(C-69)}$$

Therefore,

$$\overline{X}_{max} = \frac{0.085\ Q}{H^{2.1}} \exp\left[-\frac{1}{2}\left(\frac{H}{0.71\ H}\right)^2\right] \qquad \text{(C-70)}$$

$$= \frac{0.085\ Q}{H^{2.1}}\ (0.371) \qquad \text{(C-71)}$$

$$\overline{X}_{max} = \frac{3.15 \times 10^{-2}\ Q}{H^{2.1}} \qquad \text{(C-72)}$$

Since the AAQS for NO_x is 1.0×10^{-4} g/m^3, the NO_x severity equation is

$$S_{NO_x} = \frac{(3.15 \times 10^{-2})Q}{1 \times 10^{-4}\ H^{2.1}} \qquad \text{(C-73)}$$

$$S_{NO_x} = \frac{315\ Q}{H^{2.1}} \qquad \text{(C-74)}$$

AFFECTED POPULATION CALCULATION

Another form of the plume dispersion equation is needed to calculate the affected population since the population is assumed to be distributed uniformly around the source. If the wind directions are taken to 16 points and it is assumed that the wind directions within each sector are distributed randomly over a period of a month or a season, it can be assumed that the effluent is uniformly distributed in the horizontal within the sector. The appropriate equation for average concentration, $\overline{X}$, in grams per cubic meter is then (for $100\ m \le x \le 1{,}000\ m$ and stability class C) [26].

$$\overline{X} = \frac{2.03\ Q}{\sigma_z u x} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \qquad \text{(C-75)}$$

To find the distances at which $\overline{\chi}$/AAQS equals 1.0, roots are determined for the following equation:

$$\frac{2.03\ Q}{(AAQS)\,\sigma_z u x}\ \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] = 1.0 \qquad (C-76)$$

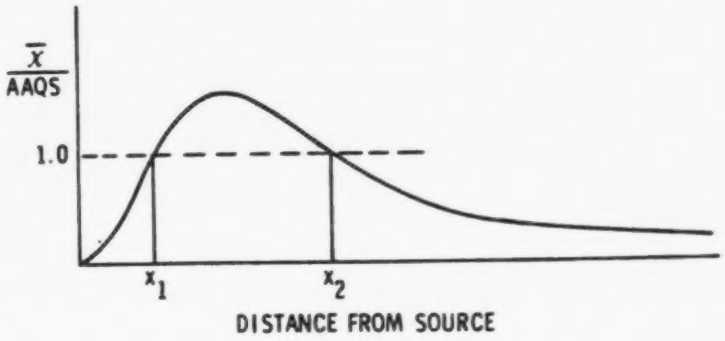
keeping in mind that

$$\sigma_z = ax^b + c$$

where a, b, and c are functions of atmospheric stability and are assumed to be selected for stability Class C.

Since Equation C-76 is a transcendental equation, the roots are found by an iterative technique using the computer.

For a specified emission from a typical source, $\overline{\chi}$/AAQS as a function of distance might look as follows:



The affected population is contained in the area

$$A = \pi(x_2^2 - x_1^2) \qquad (C-77)$$

If the affected population density is D_p, the total affected population, P', is

$$P' = D_pA \text{ (persons)} \qquad (C-78)$$

EFFLUENT SOURCE SEVERITY

Various mathematical models can be conceived to describe the impact of a discharge on a receiving body. Such systems are complex and not fully understood. Pertinent factors deserving consideration include the number of discharge streams; the flow rate and composition (chemical and physical characteristics) of each discharge stream; the hazardous nature of the discharge; the volume, flow rate, and water quality of the receiving body; and the ability of the receiving body to detoxify the discharge. In an effluent stream containing many materials, each species may have a different environmental impact; in addition, synergestic interactions may occur.

For this assessment study, it was decided to adopt a simplified approach in which the resultant concentration of a specific pollutant is compared to an associated hazard factor. Three simple models can be considered depending on the degree of mixing with the receiving body. In the first case, the source severity (S_e) was defined for each discharge as follows:

$$S_{BD} = \frac{C_D}{F_e} \qquad \text{(C-79)}$$

where S_{BD} = severity due to a pollutant in a discharge stream before dilution
C_D = concentration of pollutant in effluent, g/m^3
F_e = hazard factor, equal to a potentially hazardous concentration, g/m^3

Equation C-79 describes what may be termed the end-of-pipe severity for the discharge stream. Once an effluent enters a receiving body, it is diluted by the receiving body water and the severity decreases. The severity within a mixing zone is defined as follows:

$$S_{MZ} = \left(\frac{V_D}{V_D + F_{MZ} \bullet vr}\right)\left(\frac{C_D}{F_e}\right) \qquad \text{(C-80)}$$

where S_{MZ} = severity due to a pollutant in a mixing zone
V_D = effluent discharge rate, m^3/s
vr = river flow rate, m^3/s
F_{MZ} = fraction of river flow in mixing zone; i.e., 1/3, 1/4

The severity after the mixing zone, S_{AMZ}, is given by:

$$S_{AMZ} = \left(\frac{V_D}{V_D + vr}\right)\left(\frac{C_D}{F_e}\right) \qquad \text{(C-81)}$$

where S_{AMZ} = severity due to a pollutant after a mixing zone

These relationships are shown in Figure C-1.

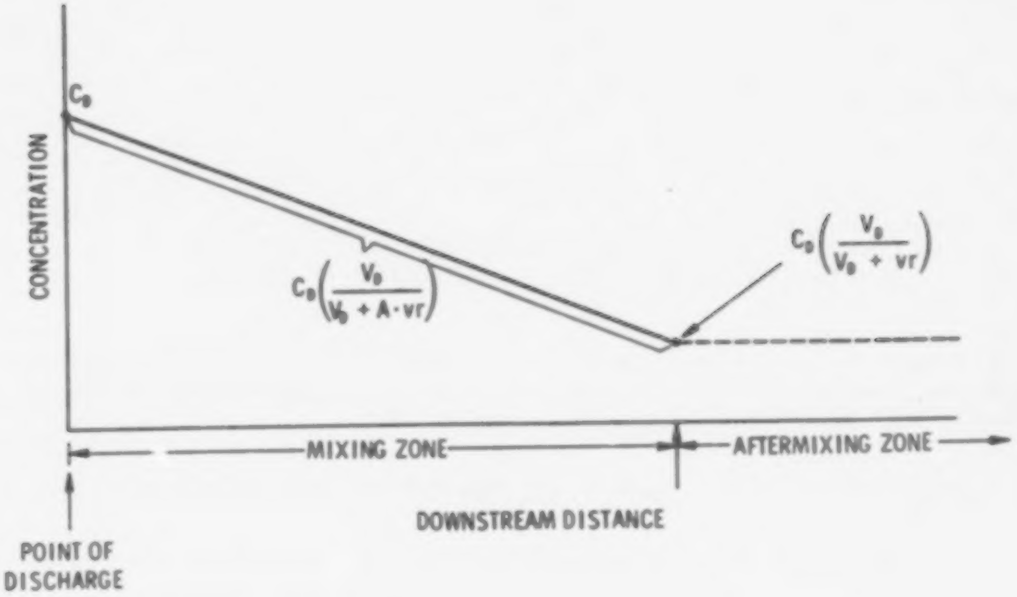


Figure C-1. Change of concentration with distance.

If vr is much greater than V_D, then

$$S_{AMZ} = \left(\frac{V_D}{vr}\right)\left(\frac{C_D}{F_e}\right) \qquad \text{(C-82)}$$

Equation C-82 defines the effluent source severity, S_e, used in this report with one exception. The term vr was replaced with the minimum river flow rate, V_R, to maximize the severity term. It is important to note that this effluent source severity is not an aggregate parameter; instead, it refers to one pollutant within one discharge stream. A more detailed treatment of the effluent source severity is available in the literature .

APPENDIX D

LOCATION OF WOVEN FABRIC FINISHING PLANT AND POPULATION DENSITIES OF SURROUNDING AREAS

The following table summarizes the number of woven fabric finishing plants, percentage of industry, production and average population density around a plant for each state.

TABLE D-1. SUMMARY OF PREDICAST AND POPULATION DENSITY DATA (A-1 1970 CENSUS, A-2 PREDICAST)

State	Number of plants	Average population densities for counties in which plants are located people/km^2	Percentage of total number of plants, percent	Percentage of industry production, percent
Alabama	1	23.0	0.3	2.07
Arkansas	1	26.3	0.3	0.45
California	10	1,138.4	3.3	2.40
Connecticut	11	203.6	3.6	6.16
Delaware	2	340.5	0.7	1.17
Florida	2	128.3	0.7	0.19
Georgia	11	62.3	3.6	7.37
Illinois	5	1,820.6	1.7	0.63
Kentucky	2	505.2	0.7	0.14
Maryland	2	397.5	0.7	1.36
Massachusetts	24	707.4	7.9	11.89
Minnesota	2	371.8	0.7	0.19
Missouri	1	7.8	0.3	0.15
New Hampshire	3	87.6	1.0	1.62
New Jersey	58	1,664.2	19.1	16.65
New York	38	11,840.7	12.2	8.86
North Carolina	40	104.2	13.2	28.21
Ohio	2	1,016.1	0.7	1.07
Oklahoma	2	267.8	0.7	0.54
Pennsylvania	23	2,888.2	7.6	3.72
Rhode Island	22	382.7	7.3	7.60
South Carolina	28	44.9	9.2	45.16
Tennessee	2	367.6	0.7	1.84
Texas	1	37.8	0.3	0.37
Virginia	7	32.9	2.3	9.64

APPENDIX E

ANALYTICAL RESULTS
129 PRIORITY POLLUTANTS

1. Acenaphthene
2. Acrolein
3. Acrylonitrile
4. Benzene
5. Benzidine
6. Carbon tetrachloride
7. Chlorobenzene
8. 1,2,4-Trichlorobenzene
9. Hexachlorobenzene
10. 1,2-Dichloroethane
11. 1,1,1-Trichloroethane
12. Hexachloroethane
13. 1,1-Dichloroethane
14. 1,1,2-Trichloroethane
15. 1,1,2,2-Tetrachloroethane
16. Chloroethane
17. Bis(chloromethyl) ether
18. Bis(2-chloroethyl) ether
19. 2-Chloroethyl vinyl ether
20. 2-Chloronaphthalene
21. 2,4,6-Trichlorophenol
22 *p*-Chloro-*m*-cresol
23. Chloroform
24. 2-Chlorophenol
25. 1,2-Dichlorobenzene
26. 1,3-Dichlorobenzene
27. 1,4-Dichlorobenzene
28. 3,3'-Dichlorobenzidine
29. 1,1-Dichloroethylene
30. 1,2-*trans*-dichloroethylene
31. 2,4-Dichlorophenol
32. 1,2-Dichloropropane
33. 1,3-Dichloropropene
34. 2,4-Dimethylphenol
35. 2,4-Dinitrotoluene
36. 2,6-Dinitrotoluene
37. 1,2-Diphenylhydrazine
38. Ethylbenzene
39. Fluoranthene
40. 4-Chlorophenyl phenyl ether
41. 4-Bromophenyl phenyl ether
42. Bis(2-chloroisopropyl) ether
43. Bis(2-chloroethoxy)methane
44. Methylene chloride
45. Methyl chloride
46. Methyl bromide
47. Bromoform
48. Dichlorobromomethane
49. Trichlorofluoromethane
50. Dichlorodifluoromethane
51. Chlorodibromomethane
52. Hexachlorobutadiene
53. Hexachlorocyclopentadiene
54. Isophorone
55. Naphthalene
56. Nitrobenzene
57. 2-Nitrophenol
58. 4-Nitrophenol
59. 2,4-Dinitrophenol
60. 4,6-Dinitro-*o*-cresol
61. N-nitrosodimethylamine
62. N-nitrosodiphenylamine
63. N-nitroso-di-n-propylamine
64. Pentachlorophenol
65. Phenol
66. Bis(2-ethylhexyl) phthalate
67. Butyl benzyl phthalate
68. Di-n-butyl phthalate
69. Di-n-octyl phthalate
70. Diethyl phthalate
71. Dimethyl phthalate
72. Benz(a)anthracene
73. Benzo(a)pyrene
74. Benzo(b)fluoranthene
75. Benzo(k)fluoranthene
76. Chrysene
77. Acenaphthylene
78. Anthracene
79. Benzo(ghi)perylene
80. Fluorene

81. Phenanthrene
82. Dibenz(ah)anthracene
83. Indeno(1,2,3-cd)pyrene
84. Pyrene
85. Tetrachloroethylene
86. Toluene
87. Trichloroethylene
88. Vinyl chloride
89. Aldrin
90. Dieldrin
91. Chlordane
92. 4,4'-DDT
93. 4,4'-DDE
94. 4,4'-DDD
95. α-Endosulfan
96. β-Endosulfan
97. Endosulfan sulfate
98. Endrin
99. Endrin aldehyde
100. Heptachlor
101. Heptachlor epoxide
102. α-BHC
103. β-BHC
104. δ-BHC
105. γ-BHC
106. Aroclor 1242
107. Aroclor 1254
108. Aroclor 1221
109. Aroclor 1232
110. Aroclor 1248
111. Aroclor 1260
112. Aroclor 1016
113. Toxaphene
114. Antimony
115. Arsenic
116. Asbestos
117. Beryllium
118. Cadmium
119. Chromium
120. Copper
121. Cyanide
122. Lead
123. Mercury
124. Nickel
125. Selenium
126. Silver
127. Thallium
128. Zinc
129. TCDD

APPENDIX F

HAZARD FACTORS DEVELOPED FOR USE IN WATER PRIORITIZATION

A Hazard Factor, F, may be a water criterion or a calculated value. This appendix lists the equations that are used in calculating a Hazard Factor.

Values were calculated by inserting toxicity values into a selected equation for F. Since specific toxicity indicators were not always available, several equations were required. The equations used are listed below in descending order of preference.

$$F_1 = 0.05 \times LC_{50} \text{ (96-hr)} \tag{F-1}$$

$$F_2 = 0.05 \times LC_{50} \text{ (48-hr or 24-hr)} \tag{F-2}$$

$$F_3 = 0.05 \times (LC_{Lo}, TD_{Lo}, IC_{50}) \tag{F-3}$$

$$F_4 = 2.25 \times 10^{-3} \times LD_{50} \text{ (oral/rat)} \tag{F-4}$$

$$F_5 = 2.25 \times 10^{-3} \times LD_{50} \text{ (other than oral/rat)} \tag{F-5}$$

$$F_6 = 2.25 \times 10^{-3} \times (LD_{Lo}, TD_{Lo}) \tag{F-6}$$

$$F_7 = 7.76 \times 10^{-2} \times TLV \tag{F-7}$$

where $F_1 \ldots F_7$ = hazard factors

LC_{50} = lethal concentration of a substance that will kill 50% of a group of experimental insects or animals
LC_{Lo} = lowest published lethal concentration
LC_{Lo} = lowest published toxic concentration
IC_{50} = concentration of a substance that will immobilize 50% of a group of experimental insects or animals
LD_{50} = lethal dose of a substance that will kill 50% of a group of experimental insects or animals
LD_{Lo} = lowest published lethal dose
TD_{Lo} = lowest published toxic dose
TLV = threshold limit value

The equations were ranked according to evidence from scientific studies and the relative availability of specific toxicity indicators [41].

APPENDIX G

HAZARD FACTORS DEVELOPED FOR USE IN SOURCE SEVERITY CALCULATION OF STATIONARY WATER POLLUTANT SOURCES

TABLE G-1. HAZARD FACTORS DEVELOPED FOR USE IN SOURCE SEVERITY CALCULATION OF STATIONARY WATER POLLUTANT SOURCES

Pollutant	Toxicological data,[a] mg/kg	Equation used to get a hazard factor	Hazard factor, g/m^3	Reference	Comments
Conventional and nonconventional					
TOD	None available	F = Cs - DO[b]	5.2		
TSS	None available		25	7	Quality criteria for water.
Sulfide	None available		0.002	7	Quality criteria for water.
Oil and grease	None available		0.01	7	Quality criteria for water.
Priority pollutants					
Acenaphthene	TD_{Lo} (skin/mus): 600.000	B-6	1,350	7	
Chlorobenzene	LC (96): 29.0 FM	B-1	1.45	7	
1,2,4-trichlorobenzene	TLm (96): 1	B-3	0.05	9	Aquatic toxicity rating TLm 96: 10-1 ppm.
p-chloro-*m*-cresol	LD_{Lo} (oral/rat): 500	B-6	1.12	9	
Chloroform	LD (oral/rat): 300	B-4	0.675	7	
1,2-dichlorobenzene	LD (oral/rat): 500	B-4	1.12	7	
1,4-dichlorobenzene	LD (oral/rat): 500	B-4	1.12	7	
1,2-dichloropropylene	TLm (96): 10	B-3	0.50	9	Value for 1,3 dichloropropylene; Aquatic toxicity rating TLm 96: 100-10 ppm.
Ethylbenzene	LC (96): 29 BG	B-1	1.5	7	
Methylene chloride	LD (oral/dog): 3,000	B-6	6.75	7	
Dichlorobromomethane	LD (50) (oral/rat): 5,000	B-4	11.25	9	Used value for bromochloromethane.
Trichlorofluoromethane	1,000	Value x 0.05	50	7	
Napthalene	LC (96): 150 MF	B-1	7.5	7	
N-nitroso-di-n-propylamine	LD (50) (oral/rat): 480	B-4	1.08	9	
Pentachlorophenol	LC (96): 0.19 FM	B-1	0.0095	19	LC_{50} (96).
Phenol	None		0.001	7	Quality criteria for water.
Bis(2-ethylhexyl) phthalate	LD (50) (oral/rat): 31,000	B-4	69.8	9	
Di-n-butyl phthalate	TLm 96: 100	B-3	5.0	9	Aquatic toxicity rating TLm (96): 1000-100 ppm.
Diethyl phthalate	LD_{Lo} (oral/rbt): 1000	B-5	2.25	9	
Dimethyl phthalate	LD (oral/rbt): 4,400	B-5	9.90	7	
Anthracene	LD_{10} (animals): 500	B-6	1.13	7	
Pyrene	LD_{10} (animals): 500	B-6	1.13	7	
Toluene	LC (96): 44 FM	B-1	2.2	7	
Trichloroethylene	LD (oral/rat): 4,920	B-4	11.1	7	
α-BHC	LD (oral/rat): 88	B-4	0.20	9	

(continued)

TABLE G-1 (continued)

Pollutant	Toxicological data, mg/kg	Equation used to get a hazard factor	Hazard factor, g/m^3	Reference	Comments
Priority pollutants (cont'd)					
Antimony	LD (oral/rat): 100	B-4	0.225	7	
Arsenic	None available		0.050	7	Quality criteria for water.
Beryllium	None available		0.011	7	Quality criteria for water.
Cadmium	None available		0.010	7	Quality criteria for water.
Chromium	None available		0.050	7	Quality criteria for water.
Copper	None available		1.0	7	Quality criteria for water.
Cyanide	None available		0.005	7	Quality criteria for water.
Lead	None available		0.05	7	Quality criteria for water.
Mercury	None available		0.002	7	Quality criteria for water.
Nickel	None available		0.0013	7	Quality criteria for water.
Silver	None available		0.05	7	Quality criteria for water.
Zinc	None available		5.0	7	Quality criteria for water.
Other metals					
Aluminum	TD_{Lo} (rpl-rat): 90	B-5	0.202	9	Used value for aluminum oxide.
Barium	None		1.0	7	Quality criteria for water.
Boron	None		0.750	7	Quality criteria for water.
Calcium	LC (96): 160 MF	B-1	8.0	7	
Cobalt	TLV: 0.1 mg/m^3	B-7	0.008	7	
Iron	None		0.3	10	
Magnesium	LD_{Lo} (oral/dog): 230	B-6	0.518	7	
Manganese	None		0.050	7	
Molybdenum	LD (50) (scu/mus): 266	B-5	0.60	9	
Sodium	None		250	7	
Silicon	TLm (96): >1000	B-1	50	9	Sand, Aquatic toxicity rating.
Tin	TLV: 0.1 mg/m^3	B-7	0.01	7	Organic tin.
Phosphorus	None		0.001	7	Elemental phosphorus.
Titanium	15 mg/m^3	Value x 0.05	0.75	7	
Vanadium	LC (96): 55 FM	B-1	2.8	7	Used the value of vanadium peroxide.

[a] Abbreviations used:

BG - bluegill
FM - Fathead minnow
MF - mosquito fish
rbt - rabbit
scu - subcutaneous

[b] Cs = saturated dissolved oxygen concentration of the receiving steam = 10.2 g/m^3 (assumed for river water at 15°C [8].
DO = dissolved oxygen freshwater quality criterion = 5 g/m^3 [7].

APPENDIX H

CHEMICALS USED IN TEXTILE PROCESSING

The textile industry is comprised of many separate processes that utilize hundreds of different chemicals. A partial list of the chemicals used during mechanical processing, scouring or dry cleaning, finishing, and dyeing follows:

A. Mechanical Processing (Lubricants)

Natural
- Mineral oils
- Castor oil
- Neatsfoot oil
- Olive oil
- Peanut oil
- Sperm oil
- Sunflower oil

Synthetic
- Polyethylene/propylene oxide copolymer

B. Scouring and Drycleaning

Scouring and Drycleaning
- Carbon tetrachloride
- Hydrocarbon solvents
- Perchloroethylene
- Trichloroethylene
- Petroleum solvents
- "Shell Clean"
- White spirit
- 1,1-dichloroethylene
- Alkylarylsulfonate

Desizing
- Bacterial amylase
- "Ensize"
- Malt extract
- Pancreatic amylase

C. Finishing

Stiffening/Sizing Agents

- Cellulose derivatives:
  - Alkali-soluble cellulose solutions
  - Carboxy-methyl cellulose (CMC)
  - Dispersible cellulosic ethers, etc.
  - Hydroxyethyl cellulose
- Gum and gelatins
- Starches (corn, potato, wheat, etc.)
- Thermoplastic resins:
  - Polyacrylate
  - Polymethacrylate
  - Polystyrenes
  - Polyvinyl acetate
  - Polyvinyl alcohol
  - Styrene-maleic acid copolymer, etc.
- Thermosetting resins:
  - Dimethylol urea
  - Melamine-formaldehyde resin
  - Monomethyl dimethylol urea, etc.
  - Urea-formaldehyde resin
  - Talla-base wax

Textile Coating Materials

- Formaldehyde resins
- Polyvinyl chlorides
- Vinyl acetates
- Vinyl and acrylic copolymers
- Vinyl butyral
- Vinylidene chloride

Hygroscopic Agents

- Ethylene glycols
- Glucose
- Glycerol
- Urea

Shrink-Resistant Agents

- Cyclic alkyl urea-formaldehyde condensates
- Glyoxal
- Hydroxy ethyl cellulose-formaldehyde complexes
- Methylated methylol melamines
- Tetra methylol acetylene diurea
- Urea- or melamine-formaldehyde resins

Anti-Slip Finishes

- Colloidal silica dispersions
- Rosin derivates + zinc acetate
- Urea-formaldehyde or melamine-formaldehyde resins
- Various vinyl and acryl resins

Antistatic Finishes

- Cationic quarternary ammonium salts
- Fatty amines and their esters
- Glycerine
- Magnesium chloride
- Modified copolymer
- Polyalkylene oxide
- Polyethylene glycol

Crush/Wrinkle-Resistant Finishes

- Ammonium and amine salt (catalyst)
- Borates
- Cyclic alkyl urea-formaldehyde monomers
- Dicyano diamine (malodor inhibitor)
- Dimethylol urea
- Formaldehyde
- Melamine-formaldehyde monomers
- Silicates
- Stannates
- Urea (malodor inhibitor)
- Zinc chloride (catalyst)

Flame-Retardant Finishes

- Borax + boric acid
- Modified synthetic polymer (halogen and/or phosphorus)
- Tetrakis hydroxymethyl phosphonium chloride (THPC)
- Triethanol amine
- Trimethylol melamine
- Trisaziridinyl phosphine oxide (APO)

Moth-Proofing Agents

- Bis-2-hydroxy-5-chlorophenyl methane (G4)
- Cadmium soaps
- Copper naphthenates
- Cuprammonium compounds
- Dieldrin
- Halogenated and phenylated phenol (Dowcides)
- Naphthalene, camphor, and paradichlorobenzene (repellents)
- Phenyl mercurials
- Salicylanilide
- Shelltox fumigant strip
- Sodium, magnesium, or ammonium fluosilicates
- Triphenyl methane
- Triphenyl phosphines
- Zinc chloride

Soil-Resistant Finishes

- Acrylate or methacrylate copolymers
- Fluoro chemicals
- Perfluoro octanol + acrylic acid
- Silicones

Water-Repellent Finishes
- Fluorine containing water and oil repellents
- Modified melamine-formaldehyde urea
- Silicones with reactive group
- Stearamide methyl pyridinium chloride
- Stearoxy, methyl pyridinium chloride
- Wax alubumin + wax caseine

D. Dyeing

Dye Accelerants or Carriers
- Aromatic esters and ethers
- Biphenyl
- Butyl benzoate
- Butyl benzyl benzoate
- Chlorobenzenes
- Cyclo carboylic acid esters
- Methyl salicylate
- Methyl or dimethyl phthalates
- O- and P-phenyl phenol
- Phenyl methyl carbinol
- Phosphated esters
- Salicylic and benzoic acids
- Orthophenylphenol

Dye Correctives
- Aromatic and alkylated aryl amines
- Diaryl- and alkaryl-substituted alkylenediamines
- Diphenyl ethylene diamine
- Formaldehyde
- Glyoxals
- Urea- and melamine-formaldehyde resins
- Zinc, magnesium, and aluminum salts of acetates and formates

Dulling Agents
- Soap cresylic acid
- Soap-pine oil emulsions

Viscosity Stabilizers
- Sodium hexametaphosphate
- Tetra-sodium pyrophosphate

Thickening Agents for Printing Pastes
- Alginates
- Cellulose ethers
- Copolymer of acrylamine and N-t-butyl acrylamide
- Dextrin
- Esters of phosphoric acid with oxyethylated wax alchols
- Esters of polyethylene glycol with long chain fatty acid and/or phosphoric acid

Ethylene oxide (modifier of starch)
Guar gums
Gum arabic
Gum traga earth
Gum tragaso
Polyacrylamide
Polyacrylic acids
Starches

Antifoaming Agents
Alkylene oxide derivaties
Fatty acid amides
Fatty acids and esters
Higher alcohols
Hydrocarbon oils
Methyl isobutyl carbinol (MIBC)
Organic phosphates
Terpins

Softening Agents and Detergents
Emulsions of oils, fats, and waxes
Fatty acid condensation products
Soaps
Substituted ammonia complexes
Sulfated alcohols
Sulfonated oil
Nonylphenoxypolyethyleneoxyethanol

GLOSSARY

affected population: Number of people living in calculated are around a plant where a given air concentration is exceeded.

ager: Box in which the dyed cloth is placed after drying to insure better color value and fastness of the dye.

bleaching: Process which whitens the textile fabric for either final finishing or light dyeing.

chemical treatment: Final finish in which the fabric is permeated with special chemicals with little additional added weight.

desizing: Process which removes the heavy size material that is applied during weaving to prevent thread and yarn breakage.

durable finish: Any finish, most commonly water resistant finishes which can withstand numerous launderings.

dyeing: Process, with many variations in application procedures, that gives the appearance of color to fabrics.

hazard factor: Calculated pollutant safety level based upon established guidelines and predetermined safety factors.

heat setting: Process in synthetic fabric finishing that uses high temperatures to set the fibers in a given shape which will be retained until the temperature is exceeded.

J-box: Vertical wooden tunnel built in the form of a printed letter "J". Cloth enters the top of the "J" and plaits down to fill up the longer arm. It is gradually pulled out through the shorter arm in a continuous operation. A J-box can be used in place of a bin.

jig: Machine in which material is dyed in open-width by moving from one roll to another through the dye liquor until the desired shade is obtained.

kier: Equipment in which cotton is boiled with dilute caustic soda to remove impurities. Also used as a verb to describe the process.

linear yard: Standard measure of production in the textile industry that refers to the length of standard widths of fabric run through a process. The standard width varies with the process, depending on the type of equipment used.

man-made: Any fiber, of either natural or synthetic composition, that does not occur naturally in the fiber state.

mercerizing: Process in cotton finishing in which the cotton is stretched and strengthened using caustic soda.

nondurable finish: Any finish, but most commonly water-resistant finishes, that cannot withstand numerous launderings without significant loss of finish characteristics.

padding: Means of saturating the cloth with a liquid; used for dyeing, washing, starching, and finishing. In dyeing, the object of padding is uniform saturation of the goods with with the dye.

plaiting down: Method of piling material into a kier or a J-box.

printing: Process in textile finishing, often performed on a specialty basis, that adds specialized dye material in predetermined patterns.

range: Continuous machine consisting of a number of boxes or compartments through which cloth passes while operations such as scouring and bleaching are performed.

representative source: Hypothetical plant, based upon calculation of industry averages of important parameters, which is used to evaluate emissions.

resin coating: Final finish in which the fabric is covered with a heavy resin to give desired characteristics at the expense of added weight.

scouring: Process in textile finishing in which impurities are removed from the grey fabrics.

singeing: Process in cotton finishing, sometimes also used in blend finishing, by which loose fibers are removed by combustion.

slashing: Process, also known as sizing, by which yarn is coated (with starch, for example) to prevent chafing or breaking during the weaving process.

source severity: Calculated value based on hazard factors, which measures the environmental impact of pollutants on the same relative basis.

special finishing: Final processing steps undergone by textile fabrics, which include mechanical and chemical treatments and resin coatings in order to give special characteristics to the fabric.

synthetic: Fibers, and their fabrics, which are composed of man-made substances, such as plastics, that are not commonly found in nature.

tenter frame: Textile finishing drying and curing equipment that is designed to hold the fabric in place while either hot air or steam is passed over it.

white bin: Bin in which cloth is piled after being placed in a bleaching powder solution. There is a slight whitening of the shade as the cloth comes out of the bleaching solution, but most of the actual bleaching action takes place while the cloth lies in the white bin.

woven fabrics: Fabrics formed from threads or yarns by the weaving process as opposed to knitting, etc, the largest portion of the fabric being broadwoven into long bolts of various widths of cloth.

CONVERSION FACTORS AND METRIC PREFIXES (157)

CONVERSION FACTORS

To convert from	To	Multiply by
egree Celsius (°C)	Degree Fahrenheit (°F)	$t_{°F} = 1.8\ t_{°C} + 32$
ram/kilogram (g/kg)	Pound/ton	2.000
oule (J)	Btu	9.478×10^{-4}
ilogram (kg)	Pound-mass (avoirdupois)	2.205
eter (m)	Foot	3.281
eter (m)	Inch	3.937×10^{1}
eter^2 (m^2)	Mile^2	3.861×10^{-7}
eter^3 (m^3)	Foot^3	3.531×10^{1}
etric ton	Ton (short, 2,000 pound mass)	1.102
ascal (Pa)	Inch of water (60°F)	4.019×10^{-3}
econd (s)	Minute	1.667×10^{-2}

PREFIXES

Prefix	Symbol	Multiplication factor	Example
Exa	E	10^{18}	1 Em = 1×10^{18} meters
Peta	P	10^{15}	1 Pm = 1×10^{15} meters
Tera	T	10^{12}	1 Tm = 1×10^{12} meters
Giga	G	10^{9}	1 Gm = 1×10^{9} meters
Mega	M	10^{6}	1 Mm = 1×10^{6} meters
Kilo	k	10^{3}	1 km = 1×10^{3} meters
Milli	m	10^{-3}	1 mm = 1×10^{-3} meter
Micro	μ	10^{-6}	1 μm = 1×10^{-6} meter

57] Standard for Metric Practice. ANSI/ASTM Designation E 380-76$^{\varepsilon}$, IEEE Std 268-1976, American Society for Testing and Materials, Philadelphia, Pennsylvania, February 1976. 37 pp.